MADRAS.

A MANUAL OF BORING

IN THE

MADRAS PRESIDENCY

BY

K. T. B. TRESSLER,

Director of Industries, Madras

985

D1:14
N18

C

NMENT PRESS

D1:14.211
NL8

TAMIL NADU ARCHIVES LIBRARY
No. 25793
EGMORE, MADRAS

PREFACE.

THIS Manual was originally prepared by Mr. K. T. B. Tressler. It is intended to form a record of the experience up to date of the Pumping and Boring section. It is hoped that the Manual will be of use to all officers who have anything to do with boring.

MADRAS,
12*th September* 1918.

G. A. D. STUART,
Director of Agriculture.

TABLE OF CONTENTS.

		Page
Chapter	I.—Underground water and development of boring ...	1
,,	II.—Geology	6
,,	III.—Underground supplies	13
,,	IV.—The location of underground supplies	18
,,	V.—Drills	23
,,	VI.—Use of drills	31
,,	VII.—Boring tools	35
,,	VIII.—Practical hints on boring	46
,,	IX.—Cost of boring	51
,,	X.—Flow of water in sand	57
,,	XI.—Estimation of supplies	64
,,	XII.—Mapping of underground supplies	69
Bibliography ...	... ...	75

BORING MANUAL.

CHPATER I.

UNDERGROUND WATER AND DEVELOPMENT OF BORING.

The total area of the Madras Presidency is something like 91 million acres. Of this area a considerable portion consists of forest land, waste, town sites, etc., and the cultivated area is about 35 million acres. In time a good deal of waste may perhaps be reclaimed, but for the present we may assume the total extent of land susceptible of cultivation to be about 43 million acres. The total area irrigated by means of river water, wells, tanks and springs is now of the order of 10 millions of acres and possible extensions of this kind of irrigation probably do not exceed 2 million acres or so. There remain therefore some 31 million acres which it will be possible to irrigate only if further supplies of water can be discovered.

Underground supplies may be of two kinds: surface or subsoil. The former, as the name implies, are found near the surface; the latter are deeper seated. Subsoil supplies may be of three kinds: artesian, sub-artesian and non-artesian. Surface supplies are always of the last character. An artesian supply is one that rises to the surface by itself, that is, on account of underground water pressure. A sub-artesian supply is one that rises to some extent but not up to the surface: a non-artesian supply is one that does not rise at all.

Surface water is water accumulated by direct percolation from the surface of the ground. Surface water is rarely met with more than 50 feet below ground—usually not more than 10 and 20 feet below that level.

Of the rain that falls over any tract a portion is carried away by torrents or rivers and the rest sinks into the ground. Of the latter a certain portion is withdrawn again by the vegetation or is brought to the surface by capillary action and then evaporated: the rest flows downwards and accumulates in the surface strata. The percentage of the total rainfall that accumulates in this manner of course varies enormously according to the configuration of the ground and the character of the soil. If the ground is precipitous and the soil rocky, there is practically no accumulation: if the ground is flat and the soil porous, perhaps half the total rainfall may be absorbed and stored.

It will be evident that surface supplies must usually be insufficient and unreliable for irrigation purposes. An irrigated crop in India requires from 2 to 5 feet of water to bring it to maturity. Seeing that the rainfall over most of the peninsula is less than 3½ feet annually and that we cannot hope to store more than half this, even in the most porous soils, the amount of water available is inadequate for the irrigation even of crops requiring the minimum of water.

It might at first sight appear possible to get over the difficulty by irrigating only every alternate acre. As is explained later, underground water does not flow readily but supplies might be concentrated in the manner contemplated by sinking a number of wells at considerable distances apart and collecting the combined supply by means of a system of surface channels. But a scheme of this kind is only feasible in places when considerable reservoirs of underground water exist and is in any case very costly, so that it could only be employed in a very few areas.

As regards reliability, surface supplies, being limited in quantity and depending for their replenishment on the local rainfall, respond very rapidly to variations in rainfall and are liable to give out just when most required, i.e., during seasons of temporary local shortage of rain,

Of course in certain cases surface supplies may be present in sufficient quantity and be sufficiently reliable in character to serve as a source of irrigation supply, but such cases are exceptional and surface supplies should in every case be examined with the utmost caution before their utilization is decided on.

Subsoil supplies are of an entirely different character. Their catchment is usually a much larger one and the water absorbed, instead of lying in a thin sheet below the surface, collects in the middle of the basin, where the supply is accordingly concentrated and usually sufficient for irrigation purposes. The size of the catchment, moreover, makes the supply respond much less readily to variations in rainfall; and subsoil water is therefore a much more reliable source of supply than surface water. Practically there may be exceptions here also and each individual case must be treated on its merits, but in general it may be said that subsoil supplies are of use for irrigation purposes, whilst surface supplies are not. The boring work so far done has revealed the existence of several subsoil basins capable of furnishing supplies adequate for irrigation purposes. Such subsoil basins can exist only in porous sedimentary formations, of which the most important are the alluvial deposits round the deltaic mouths of existing or former rivers. Apart from those deposits, sedimentary formations are very poorly represented in South India and so far as our present knowledge goes, it seems unlikely that subsoil basins of appreciable size will be found outside the alluvial areas referred to. In hard rock, the subsoil source of supply will usually be not an underground sheet of water but rather a fissure or underground river. Such fissures may carry enormous quantities of water but they are clearly much more difficult to locate than sheets. If you strike a sheet anywhere you get your supply, whereas if a boring is made off the line of a fissure, the chances are—especially in hard rock—that water will not be met with at all.

One of the objects of boring operations is to determine what the extent of the underground water resources in this Presidency really is. This is a matter concerning which very little is at present known and very diverse views are held. Some authorities are of opinion that the total amount of underground water that can be usefully employed is so small (relatively) that it is scarcely worth taking into serious consideration as an irrigation supply. Others again think

that underground water exists in sufficient volume to provide an appreciable supply. Although such little practical evidence as has been collected tends to support the latter view rather than the former, the possibility of exhaustion must not be lost sight of. In parts of England, for instance, the chalk formation has for years yielded considerable quantities of water. Of late years, however, especially in the neighbourhood of London, pumping has been so energetically carried on that the water level has fallen permanently, in some places as much as 50 feet. The chalk deposits here are enormously thick so that there is no immediate prospect of exhaustion, but, it is clear that the drain exceeds the supply and it may be merely a matter of time—if pumping is continued at the present rate—before the supply fails. In many parts of America similar exhaustion has been observed and it does not by any means follow that because a supply is initially adequate that it will remain permanently so. We may be drawing on an accumulation of water that is not replenished as fast as it is pumped and in this case the ultimate exhaustion of the source is inevitable.

The practical utility of underground supplies depends, therefore, not so much on their initial yield as on the rate of replenishment. To determine this factor, observations extending over a series of years are required and so far we have little evidence of this character: only in one or two taluks are the borings sufficiently numerous and old to enable us even to hazard a guess. So far as these observations go, it may be said that signs of exhaustion are not yet apparent, but the possibility of exhaustion must always be borne in mind when underground sources are developed and it is wise to adopt a conservative view of the extent of subsoil supplies. The matter is one that requires a good deal more investigation before any definite opinion can be expressed, but if we assume that about one-third of the average annual rainfall or say 1 foot of water percolates, the amount of replenishment over the whole Presidency amounts to something like 4 billions of cubic feet annually. A good deal of this water is no doubt dissipated in various ways and another fraction probably accumulates in places where it cannot be utilized, but even making all these deductions, the balance available would appear to be sufficiently large to irrigate a very considerable area. If we can only utilize one-third, this in itself should suffice to irrigate some 10 million acres of land.

In the present state of our knowledge we have to be content with theories and general conclusions of the above character. More exact information regarding the possibilties of the development of underground supplies can only be furnished by actual trial, that is, by boring work itself.

The origin of the boring branch of the Department of Industries dates back to 1905. In that year whilst a pumping plant was being installed on a well near Red Hills in the Chingleput district, information was received that some years previously a borehole had been driven by the village people in that very well by means of a long jumper with startling results. A spring had been met with, and water and coarse sand had been shot from the hole with such violence that, fearing for

the stability of the well, the owner had plugged up the bore again. To test the truth of the statement a 3-inch bore was put down and at a depth of 40 feet sub-artesian water was actually struck which rose and filled the well to within 13 feet from ground level. This incident afforded strong support to the popular belief in the existence of vast sandy beds of water under the Kortaliar river basin. Towards the end of 1906, in accordance with the recommendations of the Irrigation Commission, a boring party was created by Government to assist ryots in sinking wells. This party began operations in the district above-mentioned, work being confined to the Ponneri taluk. It was placed under the orders of a special Deputy Collector and the staff consisted of one Sub-Overseer and two maistris from Pondicherry. Two sets of boring tools were provided. Initially the scheme contemplated the sinking of bore-holes only on new sites, but ryots were generally averse to spending money on uncertain attempts to find water and the work did not progress very rapidly. Subsequently the scheme was modified so as to include the improvement of water-supply in existing wells. This change was accompanied by very favourable results. Many wells which formerly dried up in the hot weather yielded a good supply when the lower sub-artesian beds were drawn upon. Applications for borings increased rapidly and four more sets were added. In many cases the flow was so copious that oil-engines and pumps were subsequently installed to lift the water.

In January 1908, after about a year's work, it was considered desirable to transfer boring work to the Department of Industries. A separate establishment was sanctioned consisting of one Upper Subordinate, one Sub-Overseer and six maistris. The maistris had to undergo previous training before they could be entrusted with the independent working of the tools. The sets previously in use had been capable of boring only to a depth of 50 feet and if water was not struck within that depth, boring had to be given up. Fresh sets were accordingly purchased to bore up to 100 feet and operations were extended so as to include the adjacent Tiruvallūr taluk. By the end of the year 1907–08, that is, after nearly two years' work, 259 borings aggregating nearly 9,000 feet in total depth had been made in the two taluks.

So far, boring had practically been confined to soft alluvial soil, harder strata having been met with in only a few cases. The success of the operations in the taluks mentioned induced Mr. Chatterton, the then Director of Industries, to attempt boring in harder rock also. Coimbatore is a district in which the sub-soil is almost entirely hard rock and in which the water-supply problem is extremely acute. Towards the end of 1908, therefore, experiments were extended to include this district also.

Meanwhile isolated borings made in connexion with the erection of irrigation plants elsewhere gave ample indications of the existence of subterranean water-bearing beds all along the East Coast, notably along the Palar and Pennar river basins. By the beginning of 1909 operations included the Chingleput, Coimbatore, Nellore and South Arcot districts and shortly afterwards Government sanctioned their gradual extension throughout the Presidency. To meet the growing

demand the staff was increased and at this time consisted of 9 supervisors and 14 maistries, the number of boring sets being increased to an equivalent number (14). A definite scale of fees was also introduced. The levy of fees was not regarded with popular approval, but the work developed all the same. By the end of the year 1909–10 the total number of borings had risen to over 600. The Coimbatore experiment showed that hand boring in hard rock was a very slow and expensive business. Beyond a depth of 50 feet, indeed, it was doubtful if hand boring could be regarded as remunerative. The sets were kept employed for long periods with little result and work began to fall into arrear. To deal with borings in hard rock, therefore, power appliances were experimentally tried. A rotary power drill was purchased early in 1911 and towards the end of the next year, a power percussion drill was added. In the next three years three more drills were added.

The power drills were certainly able to deal more satisfactorily with hard rock than the hand power ones, but their introduction added difficulties in the way of management and manipulation. For one thing, the working of a power drill calls for a much higher degree of training than that of a hand drill and the penalties for carelessness, in respect of loss of time and material, are much more severe. Then again, standing charges are high and delays expensive. With hand drills the hire is so small that ryots often allow the plant to remain idle for days on end, preferring to pay hire rather than take the trouble of arranging for labour. But the same policy applied to power drills makes the cost prohibitive. Before, therefore, power drills could be employed to practical advantage, it becomes necessary to train not only a special and highly qualified working staff, but also to get ryots to revise their ideas of time very materially.

The development of power drilling was not therefore as rapid as that of hand drilling had been, but these initial difficulties are gradually being overcome and, in the future, development in this direction is likely to prove rapid.

Meantime, the number of hand drills was also being gradually augmented, corresponding increases being made in the establishment until at the beginning of 1916 the departmental establishment consisted of 13 supervisors and 40 maistries in charge of the 33 hand-boring sets, 4 power plants and various other appliances for boring that the Department now owns.

At the present time (1916) work is in progress all over the Presidency except Malabar, South Kanara, Bellary, the Nilgiris, Chittoor and Ganjām. In Malabar there is little need for water and in the other districts mentioned, the demand has not developed.

The number of borings made during the last year has reached 650, of an aggregate depth of nearly 30,000 feet. From the beginning of operations, the total number of borings (up to 31st March 1916) has been nearly 3,500, the aggregate depth being about 135,000 feet, or over 25 miles. Of these borings, rather more than half were made for the purpose of improving existing supplies, the remainder being fresh explorations. The percentage of successes was rather

more than 60, subsoil water being met with at depth ranging from 35 to 200 feet.

The foregoing history of the development of boring work in the Madras Presidency furnishes some idea of the progress that has been made in the last eight years.

Hitherto the majority of the bores put down have been of a 'supplementary' character, that is, they have had for their object the augmentation of existing supplies. There are at present more than half a million irrigation wells in the Madras Presidency of which a very large proportion is used for irrigation purposes. The field for boring of a supplementary character is, therefore, very large and it will be many years before this field is fully developed. But a still larger, though more uncertain field lies in the opening up of areas not yet irrigated. Work of this kind has only recently been started, but in the future, as the number of power boring appliances available increases, it may be expected to develop more than the 'supplementary' variety. Where water is not at present found, its value is much higher and cultivators are prepared to stake a good deal more on the chance of finding it than are individuals who already possess a supply.

CHAPTER II.

GEOLOGY.

The Presidency of Madras (with the Native States of Mysore and Travancore) occupies the southern part of what is termed the peninsular area of India. The principal orographic features of this area are the Western Ghats, a series of scattered ranges following the eastern coast line and the Mysore and the Deccan plateaux. The peculiarity of all the main dividing ranges in the peninsula is that they are merely plateaux or portions of plateaux which have escaped denudation. Peninsular India is in fact a table land worn away by denudation and the mountain chains are merely the dividing lines left undenuded between different ranges. This remarkable absence in the peninsula of any evidence of disturbance in late geological times distinguishes it sharply from the remainder of Asia. The rock structure of South India accordingly possesses certain distinctive features for the proper appreciation of which an elementary knowledge of the more important types of rocks is necessary, as well as of their mode of deposition, subsequent deformation and metamorphosis.

The first rocks to be formed were granite and other rocks of the grantoid type, consisting of comparatively large crystals and formed as a result of the cooling of the earth's molten exterior. They are termed crystalline rocks and first came into existence as surface rocks, though material of similar composition was in later stages of the earth's history intruded into them as well as into rocks subsequently formed. Granite (the commonest rock in Madras) diorite, gabbro, etc., belong to this class of rock whether they occur as original basement rocks or

subsequent intrusives. In places, through the operation of various agencies, these rocks have acquired a banded structure and then come to be known as gneisses. When still more foliated they are called schists.

The greater part of the surface of South India consists of crystalline rocks. The map given below (Fig. 1) indicates how the crystalline

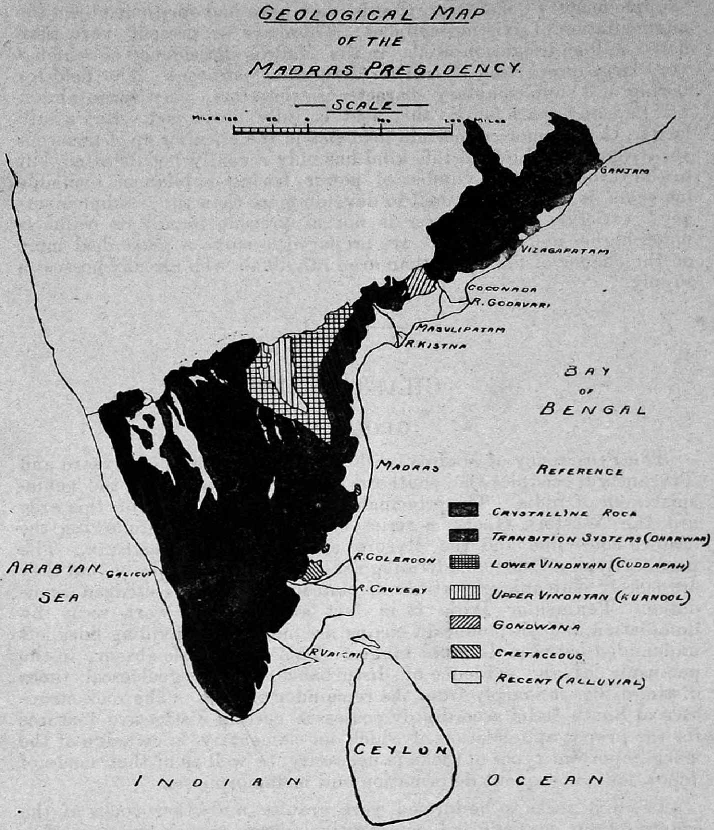


FIG. 1.

rocks preponderate. As the earth gradually cooled down the fundamental rocks composing the surface become distorted, ridges and depressions being formed. In these depressions, which we now call seas, condensed water vapour collected. The higher land surfaces,

exposed to atmospheric action suffered a certain amount of disintegration and the loose material thus formed was carried into the depressions and deposited in horizontal layers. Molten material issuing from the vents of volcanoes was often similarly deposited though at other times it also spread out irregularly over existing land surfaces or flowed into crevices.

It is to be noted that, with the exception of material of volcanic origin, irregularly deposited rocks formed subsequent to the basement rocks were laid down in horizontal bands by a process of sedimentation: rocks thus deposited are called bedded rocks.

In the process of cooling and shrinkage the earth's surface underwent further compression causing still more severe distortion, and bedded rocks originally deposited in horizontal layers were twisted into all sorts of shapes, the commonest being what are termed folds, that is, long waves, in section resembling V's or W's. These bedded rocks also underwent metamorphosis being changed into crystalline schists or even gneisses.

The bedded rocks belonging to this period are termed in India Dharwars. They consist of hornblendic and chloritic schists, phyllites and conglomerates, associated with contemporaneous trap, banded jasper, and hæmatitic quartzites. The degree of metamorphism they have undergone appears to vary considerably and to be connected with the varying and often extreme degree of compression they have undergone. Generally speaking, the beds are distinctly schistose and frequently well-characterized schists, but in places they are described as argillites, which readily weather into soft shale. The dioritic traps, which are usually found conspicuously developed in the lower part of the series, are replaced by hornblende schists in some of the highly disturbed sections.

Conglomerates are of frequent occurrence at and near the base of the system, some being of the ordinary type of true conglomerate, others consisting of boulders scattered through a fine-grained matrix. The included pebbles and boulders consist of various varieties of schist, quartz, quartzite, grit and gneiss.

The hæmatitic quartzites are composed of alternating layers of quartzite and hæmatite in varying proportions. These hæmatite beds are everywhere found in the lower portion of the system, and owing to their hardness, they stand up as sharp ridges from the softer schists, which have been denuded away from their sides, thus acquiring a conspicuousness quite out of proportion to their real importance. Rocks of the Dharwar system are not very common in the Madras Presidency. They occupy roughly a broad belt running from Mysore to Belgaum and thus cross the Bellary district. There are however numerous outliers, of which the most important are the Kolar Gold Fields and three bands running out from under the later Cuddapahs.

As a further consequence of the folding of the earth's surface, new depressions or seas and eminences were formed whose boundaries did not coincide with those of the earlier ones. Some part of the previously deposited beds, being now raised above sea level and exposed to atmospheric action, were disintegrated again and carried

away to be deposited elsewhere. In the depressions where water continued to remain, the beds were overlaid by fresh deposits. This process of elevation and denudation on the one hand, and depression and deposition on the other has been going on ever since. In some cases the areas now covered by water have always be n sub-aqueous and here the bedded strata are of enormous thickness. In others the present land surface has never sunk below water level at all and here the fundamental rocks are exposed. In South India the latter condition prevails, but there is a good deal of land surface which has at intervals been submerged and on which sedimentary strata of greater or less thickness have been deposited.

The next sedimentary deposits after the Dharwars are the Cuddapahs, the difference in age between the two being however considerable. The Kurnool rocks were laid down after another, but shorter interval.

The rocks of the Cuddapah system occupy a large area in the centre of the Presidency where the Coast line bends from a northerly to a north-easterly direction. This feature is probably connected with the form of the Cuddapah basin, which is of a roughly crescent shape, convex to the west. The north-east horn of the crescent is known as the Palnad, and reaches to Jaggayyapet, a few miles north of the Kistna river; the southern termination at Tirupati is 60 miles north-west of Madras, or only 40 measured to the outlier at Nagari Nose. Kurnool is on the northern edge and, further south, Gooty is just outside the western border. The length of the basin is about 210 miles and its width ninety-five, the area being nearly 13,500 square miles.

The eastern edge of the basin constitutes a well-defined segment of that vaguely expressed general feature known as the Eastern Ghats. The actual face of the highlands is locally known as the Veligonda ridge. It is a flanking member of the Nallamalai range, which is formed by a belt of contortion of the Cuddapah rocks along this side of their basin. The crest of the Veligonda rises to about 1,000 feet, the peaks of the Nallamalai however attaining an elevation of 3,500 feet. The rocks then again rise to form a steep range along the western margin of the basin 2,000 feet above the sea and overlooking the gneissic upland of Mysore and Bellary, the elevation of which near the range varies from 800 to 1,800 feet.

These Cuddapah rocks have the enormous aggregate thickness of 20,000 feet. But there is no continuous superposition of the different component groups at any one spot, each being local and discontinuous, overlapping the lower one or resting on the gneiss below.

The rocks of the Kurnool series lie almost entirely within the basin of the Cuddapah system, where they are found in two separate areas, the larger of which occupies the whole of the Kurnool valley and stretches to beyond the Kistna, while the other lies in the district known as the Palnad. The series has here a total thickness of only 1,200 feet: less than that of the smallest group of the Cuddapahs, and might be regarded as a member of that system, but geological indications make it fairly evident that it belongs to a distinct period.

The deposits include alternate layers of quartzites or compacted sandstones, slates or metamorphosed shales, thin conglomerates or rocks made up of consolidated and cemented pebbles. In the Kurnool formation thinly bedded limestones are also found but the alteration in all the rocks of the Cuddapah and Kurnool series is slight when compared with the great changes effected in the Dharwars. Although no fossils have been found in the former, geologists are of opinion that they represent some of the oldest members of the fossiliferous series.

After the laying down of the Kurnool rocks the country appears to have been continental for a very long period. The next rocks met with are the inland deposits of the Gondwana period. These are found chiefly in the Gōdāvari district. The Chintalapudi sandstones represent the oldest rocks of this series. They are exposed along a belt, sixteen miles wide and thirty miles long, following the course of the Gōdāvari river and terminating thirty miles west of Rajahmundry. Here they are overlaid by the Gollapalli sandstones which extend from Bimalu to near Gollapalli, a distance of fifty miles. The actual exposure of the sandstone is small as it is mostly covered by the thin Raghavapuram shales, which shales, in their turn, are overlaid by the Tirupati sandstones.

The latter formation covers a belt about forty miles long averaging about six miles in width and is overlaid by small patches of laterite Deccan trap and alluvium: also by larger patches of Cuddalore sandstones belonging to a subsequent period. There are two small isolated areas of Tirupati sandstones found, one eight miles north-west of Peddapuram and another eight miles north-west of Pithapuram. Small patches of the Gondwanas are also found south of the Gōdāvari. They occur either in the shape of plant-beds or coastal sandstones, etc., in the neighbourhood of Guntūr, Chebrolu, Polur and as far as Ongole. South of this point, up to the east of Gudur, very small deposits are met with. Larger patches again occur stretching from the east of Arkonam southwards. The more important ones are to be found at Sattiyavedu and Srīperumbūdūr in the Chingleput district. Small deposits occur also twenty miles north-north-east of Trichinopoly. Some of these patches appear as isolated deposits in the midst of granites and gneisses: others overlie crystalline rock and are themselves overlaid by subsequent rocks.

The rocks next met with belong to the cretaceous age. A small deposit of sandstones and sandy limestones occurs at Dudkur, west of Rajahmundry. It is about fifty feet thick, overlies the Tirupati sandstones and is covered for the most part by rocks of the Deccan trap series. The latter, belonging to the cretaceous age, may conveniently be noticed here. It occurs in three areas north, west and south-west of Rajahmundry. The first area is bounded by an outcrop of gneiss on the west and a deposit of Rajahmundry sandstones on the east. The second overlies the Dudkur rocks in some places and the Tirupati sandstones in others and is itself overlaid by the Rajahmundry sandstones. The third patch lies between the Tirupati and Rajahmundry sandstones. The Deccan trap series consists of bands of volcanic trap alternating with thin beds of sedimentary rocks of which limestone forms a conspicuous feature.

Sedimentary cretaceous rocks occur north by west of Pondicherry, near Vriddhachalam and between the Vellar and Coleroon rivers in the Trichinopoly district. The Madras-Trichinopoly road practically forms the western boundary of the two latter areas and runs not far to the west of the first one.

In the areas mentioned, the cretaceous rocks usually lie on the gneisses and are overlaid by the Cuddalore sandstone. In the Pondicherry area the rocks range from soft sandy bands to limestones and in the Vriddhachalam area they consist chiefly of soft sands with occasionally shaly calcareous bands. In the Trichinopoly area the rocks consist of soft conglomerates or gravel, soft sandstones and some shales and limestones. These deposits occupy an area about twenty-five miles long from north to south and about the same breadth where widest. No actual measurement of the thickness of the cretaceous rocks has been made, but an estimate of not less than 1,000 feet has been put forward. The Gondwana and Cretaceous rocks mentioned above all lie nearly flat, dipping generally at 6° or less to the south-east or south-east by east, i.e., towards the sea.

The relative age of the two deposits next met with is a matter of some uncertainty. It has been suggested that the Cuddalore sandstones belong to the late tertiary period and that laterite represents a later formation, but this is a controversial point which it is unnecessary to enter upon here. For descriptive purposes we may take the Cuddalore sandstones first and laterite afterwards.

From the neighbourhood of Rajahmundry the Cuddalore beds have been mapped at intervals along the coast for fully 600 miles to the southward. They usually form a low slope, dipping at a very slight angle to the eastward, in the direction of the sea, and are, as a rule, much covered and concealed. To the westward they rest upon rocks of various ages and they often terminate in this direction in a low scarp. To the eastward they disappear in places beneath the alluvium of the coast but they quite as often, especially to the southward, terminate in a small cliff. Their outcrop is repeatedly interrupted by the broad alluvial valleys of rivers, and in some places, as for nearly 100 miles south of Madras, they appear to be wanting altogether, whilst in other parts of the country they form a broad tract, usually sandy and infertile, raised above the general level, occasionally no less than 25 miles wide from east to west, as near Cuddalore, but generally much less.

From the paucity of sections and the extent to which the Cuddalore sandstones are concealed by laterite and sandy soil, their absolute thickness can nowhere be estimated with accuracy. The scarp in which they terminate to the westward is sometimes as much as 100 feet high and they must be somewhat thicker than this, but it is doubtful if they attain any considerable thickness. They are perfectly undisturbed, and have every appearance of being a comparatively late formation.

On the Malabar coast from Calicut southward to Cape Comorin is a belt, 10 or 12 miles wide, of rocks similar to the Cuddalore sandstones but believed to be slightly older.

Laterite is a well-known formation and has a characteristic appearance which makes it easily recognized. Its scoriaceous structure bears a curious resemblance to an igneous product but it has been proved that laterite is never an original form of igneous rock. It is either produced by the alteration of other rocks or else is of detrital origin.

Several writers have divided laterite into two forms, high level and low level, the latter being regarded as of detrital origin and the former of non-detrital origin. Low level laterite is, as a rule, more homogeneous than the high level form and passes by insensible gradations into sandy clay or gravel. Not infrequently the two forms of laterite are almost indistinguishable and this fact serves to show that no hard-and-fast distinction can be drawn between the two but there is undoubtedly on the whole a difference in age and origin between the two types. In Southern India the high level laterite occurs only in a few elevated places in the Western Ghats.

The "low level laterite" occurs on the east coast of India almost everywhere, rising from beneath the alluvium which fringes the coast and sloping gradually upwards towards the interior, but this laterite is, as a rule, a much less massive formation than the rock of the western coast. It is seldom more than 10 feet in thickness, and is often represented by a mere sandy or gravelly deposit, not more than four or five feet thick. The laterite is frequently conglomeritic, and includes large rounded, or subangular, fragments of gneiss and other rocks, good instances being found at Trichinopoly, and in many places near Madras, amongst which are the Red Hills. Quartzite implements of human construction have been found in the laterite in considerable numbers.

The next and last formation is the alluvium of recent age, covering numerous and extensive areas along the many river valleys such as those of the Cauvery, Palar, Swarnamukhi, Pennar, Gōdāvari and Kistna and the large deltas opening into the Bay of Bengal. These alluvial deposits often attain a considerable thickness: borings made at Ellore to a depth of 400 feet do not reach the bottom of the formation and in the Tanjore delta 300 feet borings often fail to penetrate it. Alluvial deposits consist of alternate layers of sand, clay, gravel, or a mixture of these. The layers may be of any thickness or extent, but do not usually exceed 30 feet. The layers sometimes appear to be continuous over considerable areas: at other times they are mere pockets. When, as is usually the case, a pervious layer is, so to speak, sandwiched between two impervious ones the conditions necessary for an artesian or sub-artesian supply exist. Passing reference may also be made to the blown sand deposit that fringes the western shores of the Bay of Bengal.

This completes the catalogue of formations found in South India. It will be of interest to estimate roughly the areas covered by each formation. When a formation is exposed earlier formations may exist below but subsequent ones must necessarily be absent. Grouped in order of age the rocks met within Southern India may be arranged in the classes given in the appended table.

In this table is also given the exposed area and a rough guess at the covered area. Crystalline rocks ultimately underlie all other formations.

Rocks.	Exposed area.	Covered area.	Exposure per cent of total area.
Crystalline	97·500	47·300	67·3
Transition	1·000	...	·6
Vindhyan	13·500	17·000	9·3
Gondwana	1·500	10·000	1·1
Cretaceous	·600	5·000	·4
Alluvium	30·700	...	21·3
	144·800	...	100·0

The figures given are extremely approximate, but serve to give an idea of the relative extent of the different formations. It will be observed that the crystalline rocks preponderate and as they are the lowest formations of all it follows that over the major part of the Presidency such rocks alone exist. This indeed is the characteristic feature of the geological structure of Southern India; the absence of evidence of disturbance in late geological time as indicated by the scarcity of sedimentary deposits of the mesozoic period. Its bearing in relation to the question of underground supplies of water will be considered in the next chapter.

CHAPTER III.

UNDERGROUND SUPPLIES.

At present our knowledge of the distribution and extent of underground supplies is of a very sketchy character. The three thousand borings already put down give us some idea of where underground water exists and where it does not. The data thus furnished are however much too vague and too scanty to enable us to draw definite conclusions regarding the character of underground water supplies. A beginning has been made by the Department of Industries in the matter of instituting a scientific record of all the work done and the positions of all borings are now mapped as well as the water levels. As observations multiply, this record will in time form a reliable basis for the determination of the distribution and extent of underground water. At present the work is still in its initial stages and until it has been developed much further we must continue to depend mainly on geological indications for our knowledge of underground supplies.

In the foregoing chapter the various formations met with in this Presidency have been described and it now remains to consider them from the point of view of water-supply. It has been explained that the greater part of the land surface of this Presidency consists of crystalline rocks. There are also considerable alluvial deposits of recent age. Intermediate sedimentary formations are not well

represented. Alluvial deposits nearly always contain water but the supply is unreliable; crystalline rocks can scarcely be considered as water-bearing in the ordinary sense. In most countries the largest reservoirs of underground water are the intermediate sedimentary formations which are just the formations that are most deficient in South India. Speaking generally, therefore, the land surface of the Madras Presidency cannot be regarded as favourably constituted for the underground conservation of water.

Coming now to the different formations in detail, granite and gneiss are both compact rocks and absorb very little of the water falling on to or passing over them. Granite, however, can absorb a little more than gneiss and is also more broken by fissures. Both the rocks are often decomposed on the surface sometimes to depths of 100 to 200 feet. Water can descend through the decomposed material and on meeting a fissure below will travel along it; a fissure may thus receive much more water than its very small width would lead one to expect. These fissures are generally nearly vertical and distributed at irregular intervals.

The Dharwar rocks are usually entirely crystalline or nearly so and at times even shaly. They do not absorb much water but they are laminated, jointed and crushed, and are in this manner provided with innumerable passages for water. Owing to the sharp folding, their outcrops are small. In most places these rocks appear to be arranged like closely packed leaves in a hollow in the underlying granite or gneiss. Considerable quantities of water will often accumulate therein. These can be tapped by boring but do not reach the surface as they are not under pressure.

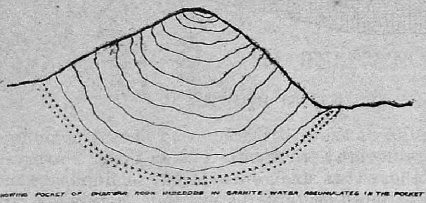


FIG. 2

showing pocket of Dharwar rock imbedded in granite. Water accumulates at the bottom of the pocket.

The Cuddapah and Kurnool rocks are also sufficiently metamorphosed to impede the progress of water through them and they are also similarly, though not quite so highly, inclined as the Dharwars. In general the conditions for finding water in them are similar to those in the Dharwars.

The Gondwana and Cretaceous rocks, the laterites and the Cuddalore sandstones present the most favourable conditions for water conservation. They are very gently inclined and therefore present wide outcrops and thus catch large volumes of rainwater; most of them are very porous and allow of the free passage of water whilst, owing to their slight inclination, they do not dip very far below the surface, the more so as the general direction of dip is the same as that of the land surface, i.e., towards the sea. For this last reason it is also possible to find water under pressure.

The diagram (Fig. 3) illustrates the conditions above described assuming (as is rarely the case) that all the formations mentioned are present. At any one place only one formation is exposed, but it does not follow that the others are wanting. They may have been entirely covered over (or overlapped) by subsequent deposits and may possibly still be met with by boring through the latter. On the other hand, a formation which by its occurrence at one spot, and by its general direction and dip would ordinarily be expected to pass under another spot, may have thinned out en route and thus be wanting. Still it will be perceived that a boring made in a recent formation, as shown in the diagram, will successively pass through several potential water-bearing strata (one or more of which may, however, be wanting) before crystalline or fundamental rock is encountered. In such a medium there are therefore several chances of striking water. If, on the other hand, we are down on crystalline rock to begin with, our only chance is surface water or a fissure within the rock itself.

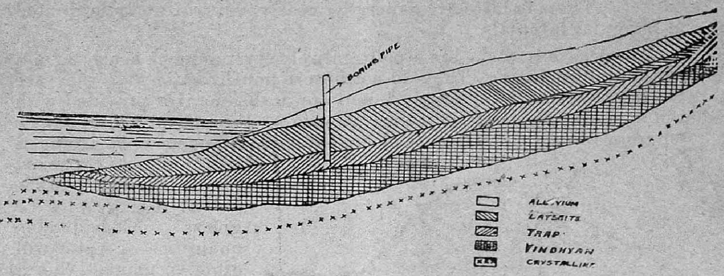


FIG. 3.

As already explained, intermediate formations as a whole are very limited in extent, and of those that are represented, Cuddalore sandstone and laterite are the most widely distributed, Gondwana and Cretaceous rocks occurring on a very much smaller scale.

Finally we come to alluvial deposits. These are all water-bearing in a greater or less degree. As previously stated they consist of alternating bands of clay, sand and gravel or a combination of these materials. Wherever sand occurs, there will almost certainly be water, but if the sand is very fine or has a large admixture of clay or silt, the water is so difficult to remove in adequate quantity that for practical purposes it may almost be regarded as non-existent. Coarse sand and gravel hold enormous quantities of water which they will readily give up and layers of this kind may be regarded as the natural reservoirs of underground water. Sometimes these layers are continuous over a considerable area and then constitute a reliable source of supply; sometimes they are mere pockets and in this case are quickly exhausted.

This alternation of pervious and impervious bands of varying thickness continues throughout the formation. The water found in the deeper beds is probably of a subsoil character but water occurring within 20 feet of the ground is usually surface water and therefore unreliable as regards quantity.

Excluding surface water, which we have an equal chance of finding whatever the formation, provided that the surface soil is sufficiently porous, we can from the foregoing description form some idea of the water-bearing possibilities of the Presidency. Speaking generally the later the surface formation, the greater the number of chances of finding water below; so also, the more porous the stratum the

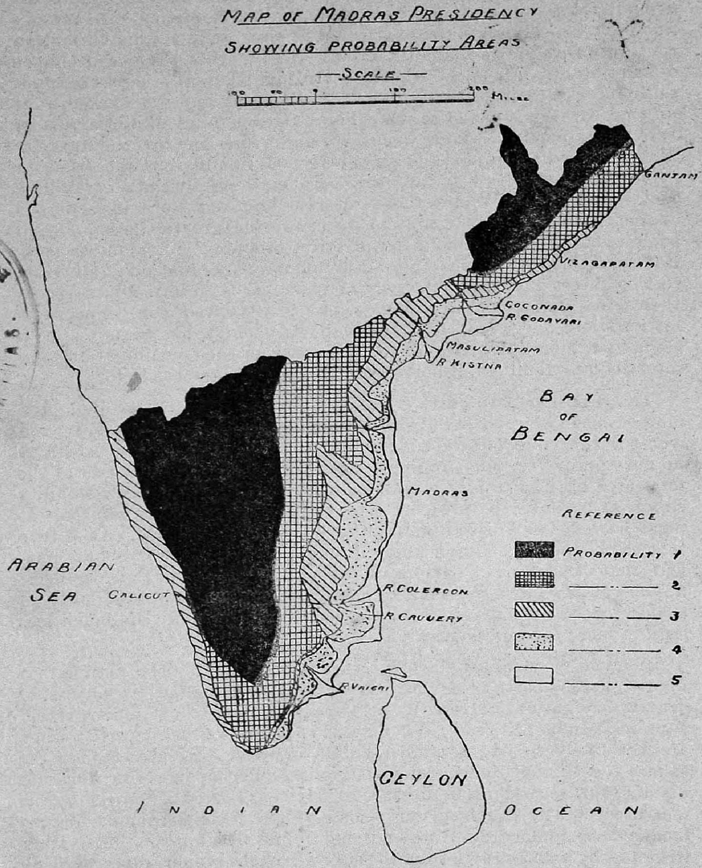


FIG. 4.

greater the prospect of finding water in useful quantities. As has already been explained, our information on underground water-supply is at present very deficient but from general considerations of strata and porosity we can construct a rough map of probable underground

water resources. Such a map being clearly of a most general character is of little direct use, more especially when the uncertain character of boring work generally is recognized. In an area when indications are all against water, we may strike an underground river and *per contra* may be disappointed in a boring sunk only 50 yards from a well now yielding water. But the map will serve a useful purpose in indicating the relative probability of the existence of underground water-supplies in different parts of the Presidency. In crystalline rock we can only hope to strike a fissure, and, as this formation continues right down to the limit of the earth's crust, there is no chance of striking any other water-bearing stratum below it. Areas of crystalline rock are accordingly the least promising and are marked as of unit probability. Going to the other extreme, alluvial deposits may hold a great deal of water themselves and, when they overlie intermediate sedimentary formations; a boring sunk in alluvium, if carried far enough, may successively tap other sources of supply until crystalline rock is reached. Where these intermediate rocks are of a porous character, the chances of finding water are the greatest possible, and such a chance is designated (arbitrarily) probability five on the map. Between these extremes there are numerous gradations: alluvium resting direct on crystalline rock, exposures of intermediate rocks, themselves porous or overlying other porous formations, impervious intermediate rocks, etc. In the map an attempt has been made to estimate the relative probability of water in each combination and intermediate numbers, from two to four, are assigned thereto.

The resulting map bears a general resemblance to the geological map given in Chapter II but shows the position as regards underground water rather more clearly. At first sight the inferences to be drawn do not appear very encouraging. Such an enormous proportion of the total area of the Presidency falls below two probability: a probability so low as to make the prospect of development extremely remote. It must however be borne in mind that boring is a gamble. It is true that the chance of striking water in unit probability areas is only one-fifth that of striking it in areas of probability five. But this argument applies to areas as a whole and does not preclude the possibility of striking good supplies in unit areas; only the probability is much less than in more favourable areas.

A much more unsatisfactory feature recorded by the map is that many of the best areas are those already irrigated by means of gravity irrigation. Here it is difficult to see how underground supplies can be utilized. When ryots can get water by gravity, they are not likely to pay a double, treble or even sixfold rate for the sake of utilizing underground supplies. Perhaps in the dim and distant future, when the pressure of the population compels heroic measures, the deltaic headworks may be moved upstream to irrigate lands where underground water is not found, leaving the deltas to be irrigated by water drawn from the subsoil. This would solve a difficult irrigation problem: that of drainage, but financial reasons alone place such a scheme beyond the sphere of practical politics for a century or so. Meantime we have to reconcile ourselves to the fact that underground supplies in irrigation areas must be regarded as wasted.

There is one point in connexion with underground supplies that may with advantage be touched upon here, namely that of salinity. Underground supplies when tapped, frequently prove so saline as to be useless for irrigation purposes. It is impossible to differentiate between saline and non-saline sources on the map and the risk of salinity is one that cannot be avoided. Water found in the lower sedimentary and crystalline formations is nearly always pure and salinity is rare in the intermediate sedimentary formations: it is in the alluvial deposits that saline water is most frequently met with. The popular explanation that salinity is due to contamination by the sea, may be touched upon here—and dismissed. The hydraulic gradient necessary to force sea water, or for that matter any other kind of water, into pervious strata precludes any possibility of such contamination extending any distance inland, and if further evidence of a negative character is required we have merely to refer to wells which have been sunk on the very edge of the beach and yielded perfectly fresh water. Salinity in underground supplies is almost invariably due to salts which have been dissolved out of the land by the water in the process of percolation. Such salinity may be cumulative. Part of the water contained in an underground reservoir is removed by capillarity in a purer state than that of the whole body of water and if the reservoir is not otherwise drawn upon, it becomes increasingly saline in time. The water so to speak has become stale but, if regularly withdrawn, may regain its freshness. It has often been found that sources which at first appeared saline have, after a few days' pumping, improved considerably in freshness. The same is true of wells. An interesting example is that of a domestic well which had been unsatisfactory for years. The mali's wife then decided to commit suicide in that well and before it could again be used for drinking purposes it was decided that a thorough cleaning was necessary. The well was accordingly pumped dry two or three times and afterwards, much to the surprise of the owners, the water was found to be quite sweet. On the other hand, water may percolate through land of such salinity that no amount of pumping can improve its quality. Saline sources are generally useless for irrigation purposes, but before condemning a source as unfit it is as well to test it first for some time and watch the result.

CHAPTER IV.

THE LOCATION OF UNDERGROUND SUPPLIES.

In the preceding chapter we have seen what indications of the presence of an underground supply the science of Geology can furnish. Such indications must perforce be of an extremely general character and, as boring is a somewhat expensive operation, the approximate location of supplies by means of surface indications only is a matter of the utmost practical interest. From the earliest times, certain individuals have laid claim to mysterious powers of detection and if these claims could be substantiated, the services of such individuals would be invaluable.

The appliance employed by 'Dowsers' as they are called is very simple, consisting merely of a stick of forked witch-hazel. This stick (of course only in the hands of an expert) is supposed to go through peculiar manœuvres in the presence of water, bending up in some cases, down in others and sometimes even performing a sort of Catherine wheel.

Although the process of 'dowsing' or water-finding is overlaid with a lot of humbug, there can be no doubt that the percentage of successes obtained is greater than that which can be attributed to pure chance. The difficulty in accepting the divining rod as a scientific water detector lies in the fact that its action is inexplicable on scientific grounds. If a witch-hazel rod is sensitive to the presence of water, as it may well be, it might reasonably be argued that it would constantly be in a state of tremor, as water in some form or other is ubiquitous. In this case, the rod would be useless as a specific indicator of underground supplies. On the other hand, if the supposed influence of water on witch-hazel is limited to water in a state of flow, some sort of scientific explanation for the action of the divining rod might be put forward. Flowing water is a source of energy, and it is quite possible that some of the kinetic energy of flow might be transformed into some other form of energy capable of influencing a particular kind of receptive body. The effect observed might also be attributed to eddy currents on the earth's surface. But water finders do not limit their claims to the detection of water in motion: on the contrary, they assert their ability not only to detect water in any state, to estimate their quantity, etc., but to detect rare metals also. In the presence of silver, for instance, the witch-hazel performs other actions than those which water induces and gold affects the 'dowser' in a still different manner.

No scientific explanation of the alleged phenomena has, so far as I know, ever been put forward. 'Dowsers' seem anxious to explain them, but their explanation is usually a compost of claptrap and odd scientific terms that may, to the ignorant, appear impressive, but is, to the scientific mind, merely ridiculous.

It seems probable that the 'dowser' is led to locate water rather by a natural instinct than by the indications of his stick. The trained geologist can, by observing the configuration of the country and the nature and lie of the rocks, usually indicate some spot or other where water is more likely to be found than in others and the conclusion that the geologist arrives at by trained reasoning and inference is probably arrived at by the 'dowser' by a natural and perhaps sub-conscious instinct.

In the same class as the 'dowsers' fall the Woddars or well sinkers of India, who, in many cases, make remarkably accurate guesses as to the location of water. These men work in a different way, but the underlying principle is probably the same in both cases.

Recently an attempt has been made to substitute a regular instrument for the time-honoured witch hazel, possibly with a view to giving 'dowsing' a more scientific aspect. This instrument consists essentially of a common galvanometer mounted on a tripod, the presence of water being indicated by the motion of the needle. This instrument

has been tried in Bombay and has, in many cases, afforded accurate indications, but neither the 'dowser' with his 'magnetic' instinct nor the galvanometer needle can be regarded as anything like infallible water detectors. It must be remembered that it is not sufficient to prove that water *always* exists at the spots indicated by the human or electrical water-finder. To establish a case for infallibility—or something approaching thereto—it is necessary also to prove that water *never* exists at spots where the water-finder does not give any indications. On this point little evidence exists.

Without such assistance as the 'dowser' claims to be able to render, the detection of supplies becomes merely a matter of trial and error. The intelligent individual will take note of geological details: of patches of green in otherwise arid tracts, of depressions, faults and so on and will select his site accordingly. The unintelligent individual will bore blindly. The former type of individual will have a greater percentage of successes than the latter, but in both cases the location of supplies is merely a matter of guess work, more or less intelligent, and as such it must be regarded.

In alluvial tracts there is usually little difficulty in locating underground supplies. In the numerous cases also when an existing well is to be improved by boring, no special means of detection are required. Again when a large number of wells already exists, it is generally possible to get a pretty accurate idea of the distribution of underground water by mere inspection. In other cases the location of underground supplies by means of surface indications is a matter of extreme difficulty. A knowledge of the geology of the district may afford a certain amount of assistance and the natural features of the country may furnish a rough indication of the probable whereabouts of underground water, but this is all the prima facie evidence available and when this has been weighed up, the only thing to be done is to choose the most likely site and sink a trial boring. If this proves a failure, another must be sunk and so on until water is actually tapped.

It is clearly impossible to lay down any general principles to be observed in selecting a site for a bore-hole and beyond emphasising the necessity for a careful geological study of the district operated in and the unstinted application of common sense, science seems at present unable to furnish the would-be prospector with any assistance. The employment of a 'dowser' may improve the chances of success and on the same principle as backing two horses in the same race, a cautious individual might find it worth while paying a small fee to a 'dowser' for his services. But it must be borne in mind that both horses may prove outsiders and it is foolish to attach too much credence to the usually inflated claims of the 'dowser'. Ten per cent of the estimated value of the boring is the utmost that I personally regard his advice as worth.

We see therefore that surface indications and the mysterious skill of the water finder may *help* us to select a site for boring but to *prove* the accuracy of the guess a trial boring must be made. In other cases when there are no indications and water has to be searched for by a process of trial and error, trial borings also have to be made.

Hence whether there are indications or not, boring has to be resorted to in every case for verification purposes. It is necessary however to emphasise the fact that boring of this character—trial boring as it is termed—is primarily intended only to verify or locate underground supplies and not to furnish a supply of water. In some cases indeed, the supply derived from a trial boring may suffice for requirements. But such cases should be regarded as exceptional, though frequent, and the original trial boring should in general be looked upon as of a purely exploratory character, the development of the supply thereby revealed being a subsequent operation. The most usual way of developing the supply is to dig a well, put in an enlarged bore-pipe or sink some form of perforated tube.

In order to ascertain how far the supply revealed will be useful for the purpose for which it is intended it is clearly necessary to find out what it will yield. As however the boring made in the first instance is merely a trial boring it is not sufficient to know what its actual discharge is: What we require to know is what the discharge *will be* when the bore is developed. The problem of estimating supplies is dealt with in a subsequent chapter but one or two fallacies connected with the problem of supply may be touched upon here.

It is obvious that water can enter a bore pipe only from the bottom and that all strata above that in which the end of the pipe rests are sealed by the pipe. A bore may pass through two or three water-bearing strata, but only the lowest of these; the one in which the end of the pipe rests, can be drawn upon for a supply. One way of developing a boring is to substitute a perforated pipe for the original boring pipe, thus making it possible to draw upon a much larger source of supply. For this purpose the so-called convoluted pipes made at the Public Works Workshops, Amritsar, and also by one or two private firms in Northern India are very largely used. These pipes are useful inasmuch as they offer a much larger area for percolation and therefore enable the water to be withdrawn from the water-bearing stratum a good deal more easily than is possible with a bore pipe. In this respect they are to be preferred to ordinary lining pipes as also on account of their ability to tap strata which would otherwise be sealed. There, however, appears to be a popular idea that the use of such tubes increases not only the rate of discharge but also the total yield. This view is fallacious.

When water is pumped from a well or borehole, it is found that the water level in the soil immediately round the borehole begins to sink as pumping progresses. The depression becomes less the further we recede from the borehole and at some considerable distance the subsoil water level is unaffected. In other words, when subsoil water is pumped, the water level is changed and assumes the form of a cone of revolution with its axis on the bore or well pumped from. The cone, called the cone of exhaustion, gradually increases in size as pumping progresses.

It has been found that the flow of water in sand becomes inappreciable when the hydraulic gradient falls below 1 in 200 or so. It follows therefore that the cone of exhaustion can only be extended until the sides stand at about this angle and the volume of such a

cone represents the maximum amount of water that can be drawn from the well or borehole until the supply is replenished by floods, seasonal rains, etc. The total quantity of water that can be withdrawn between such seasons of replenishment from a given point in a water-bearing stratum is therefore practically a fixed quantity which is independent of the way in which pumping is done or the nature of the well or borehole. The only difference between different methods of withdrawing water will be in the *rate* at which the supply can be withdrawn.

The use of perforated tubes or other devices may improve the discharge of a bore, but it cannot affect the total yield.

The distinction between yield and discharge is one that is not always appreciated and thus misconceptions of the above kind arise. The discharge is the *rate* at which water can be withdrawn and this depends, amongst other things, on the character of the well or borepipe. But the yield of a well, that is the *total* amount of water that can be obtained from it, is practically independent of the way in which water is pumped.

It is the aim of most cultivators to obtain the greatest possible discharge under the impression that, by so doing, they obtain the maximum amount of water from the well. This again is a fallacy. Within limits the argument holds good, but beyond these limits it does not. If, for instance, a well is being pumped from by means of a 3-inch pump, it will generally be found that after the water level has fallen some 4 or 5 feet, it remains practically stationary for a considerable period. If a larger pump is employed, the water level falls more rapidly and continues to fall below the previous level. Thus it often happens that, in a comparatively short space of time, the well becomes dry or the water level falls below pumping limits. If this happens, the total amount of water that can be obtained during one complete period may be considerably less with the larger pump than in the smaller one.

To take a concrete example. It was found in a certain well that with a 3-inch pump the water level fell 6 feet and then remained practically stationary. With a 4-inch pump the level fell by 14 feet in 4 hours (beyond which it was impossible to pump). The 3-inch pump gave a discharge of about 180 gallons a minute and the 4-inch pump about 320. On a 4-hour pumping shift the smaller pump accordingly yielded 430,000 gallons and the larger one 770,000 gallons. But after 4 hours' pumping it was impossible to work the 4-inch pump again until the water level had recovered, which took about 20 hours. After 12 hours' pumping with the smaller one, the water level had fallen by 8 feet, the discharge during this period amounting to rather more than 1¼ million gallons. The well recovered its original level in about 12 hours. Thus taking the full period of 24 hours, the smaller pump yielded more than 1¼ million gallons whereas the larger pump yielded only ¾ million, although the discharge in the latter case was considerably greater than that in the former.

Another very common fallacy is to suppose that the water-supply can be materially improved by sinking two wells close together. If the wells are sufficiently far apart, they will serve as independent

sources of supply but, if their cones of exhaustion overlap, then the water level in the one well will sink when pumping is being done from the other and the total yield that can be obtained from the two is little greater than that from a single one. Taking the figure already given for the angle of repose of water in sand, namely, 1 in 200, it follows that if a well be 20 feet deep, its cone of exhaustion will extend over a radius of 2,000 feet and any well sunk within this area will be interfered with by pumping from the first well. On the extreme limits of the area the interference will, of course, be small, but, in general, it may be said that wells within a quarter of a mile of each other are likely to cause so much mutual interference, if power pumping is resorted to, as to make the two of little more value than a single one.

Another form of the same fallacy is the idea that the discharge of a well can be materially improved by increasing its diameter. When the supply is inadequate, ryots very often spend enormous sums of money in enlarging their well and are disappointed to find that their supply has not been improved in anything like a reasonable proportion to the cost of the work done. The deepening of a well will always increase the supply, provided, of course, that the underlying stratum is porous, but a mere increase in diameter beyond a certain limit helps very little except in so far as it affords extra storage accommodation and so furnishes a reserve to pump from. When a well is very small, say less than 6 feet across, the area through which water can percolate into the well is very small and the velocity is therefore comparatively large, leading to a certain amount of choking in the passages by which water gains access to the well. This, however, is purely a mechanical difficulty which is overcome by increasing the diameter so as to reduce the velocity of approach. When the diameter has been increased to 10 or 12 feet, the velocity is sufficiently reduced to avoid choking and after that a further increase in diameter has little effect on the rate of supply. This fact is further proved by the formulæ given in Chapter X.

F llacies of the above character are very common and have been specially noted because they are still very generally believed and this belief leads to a considerable and unnecessary waste of money, time and energy.

CHAPTER V.

DRILLS.

There are two systems of drilling, rotative and percussive. In the former system the material is cut out with a circular motion, like cheese with a scoop : in the latter it is broken by an up and down percussive motion. A combination of the two systems is often adopted, the method of boring followed in any particular case being determined mainly by the nature of the soil worked in. When the soil is very soft, 'sludging' or washing out is a process that can often be advantageously employed.

Drills may be operated mechanically or worked by hand. As previously explained, the use of hand drills is limited to comparatively shallow depths. They do not work very well in hard rock, but are portable and cheap and are therefore to be preferred in shallow borings and when the nature of the soil permits of their use. Power drills can bore to any depth but for irrigation purposes borings, in South India at any rate, are rarely sunk more than 300 feet.

The three standard drills adopted by the Department are as follows:—

1. Hand drill—to bore up to 100 feet;
2. Power drill—Rotary } To bore up to
3. Power drill—Percussion } 350 feet.

Deeper borings are not at present being attempted but the depths above given may, in certain cases, be exceeded 50 per cent as explained in Chapter VI.

Hand drills.—The mechanism of a hand drill is extremely simple consisting merely of a set of shear legs, wynch and a pulley over which the working rope passes. The pulley is slung from the top of the shear legs centrally over the borehole, one end of the rope being attached to the swivel head or hook attached to the string of working tools and the other to the wynch. The wynch serves to give the tools an up and down motion or to withdraw them. The arrangement is shown diagramatically in Plate I. The shear legs usually consist of casuarina poles 30 to 32 feet long and 10 inches diameter at the thicker end, tapering to 6 or 7 inches at the top. They are connected by means of a crowbar 3 to 4 feet long and $1\frac{1}{4}$ to $1\frac{1}{2}$ inch diameter passing through holes made in the top of the legs. The pulley is slung from the crowbar. It is usually 8 to 10 inches in diameter and of sufficient size to pass the rope or tool line which is 4 to 5 inches in circumference and 80 to 100 feet long. Only best manilla ropes are used as inferior ropes wear out much more rapidly and do not prove economical in the long run.

In the place of casuarina poles wrought iron shear legs are also used, especially in places where casuarina poles cannot be obtained. The only advantage they have is that they are more easy to carry about. On the other hand, as the tubes are much smaller in diameter (3 inches), they have to be stayed in order to give them the necessary rigidity.

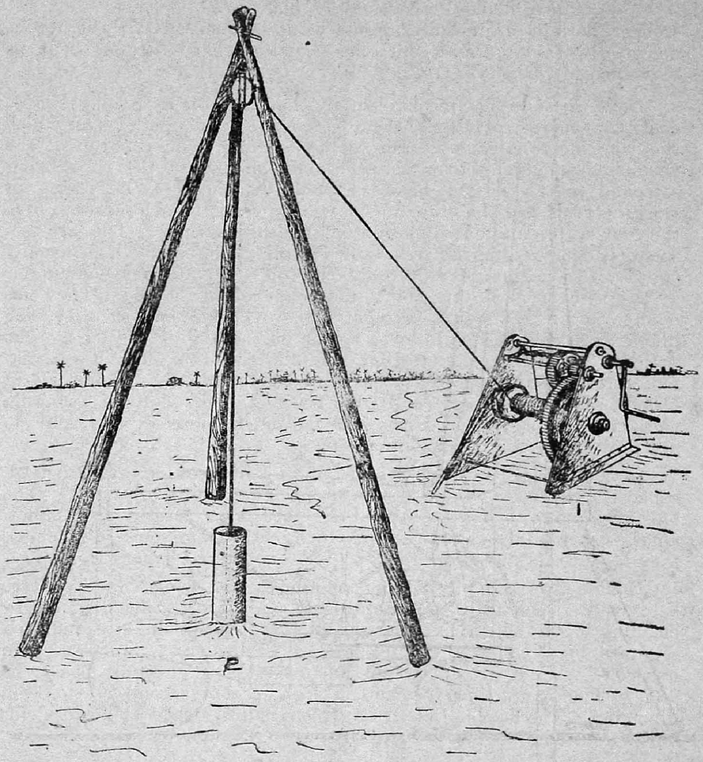
Double sheaved pulleys are sometimes used when two ropes are employed. Such an arrangement is convenient when much baling or cleaning has to be done. The cleaning tools are then attached to a separate line (called the sand line) and it becomes unnecessary to unscrew the tools from the tool line every time cleaning has to be done. The sand line is a much lighter rope, from $2\frac{1}{2}''$ to $3''$ in diameter. The double line arrangement is universal with power drills but is not much used with hand drills.

The wynch is of the double purchase variety and has a normal lifting capacity of 5 tons. As such wynches are in common use, they require no special description.

This completes the mechanism of the hand power drill: the tools and their uses are explained in the next chapter.

The *modus operandi* is as follows:—Where rotary drilling is proposed, a series of lengthening rods are attached to the hook and the tool is screwed to the bottom of these. The string of tools is then lowered into the borehole by means of the winch and the rods are rotated by hand. When the tool is to be changed or the borehole cleaned, the string of tools is lifted as far as possible and the top section of lengthening rod is disconnected. The remaining sections are then successively lifted and unscrewed until the whole string of tools has been removed from the borehole.

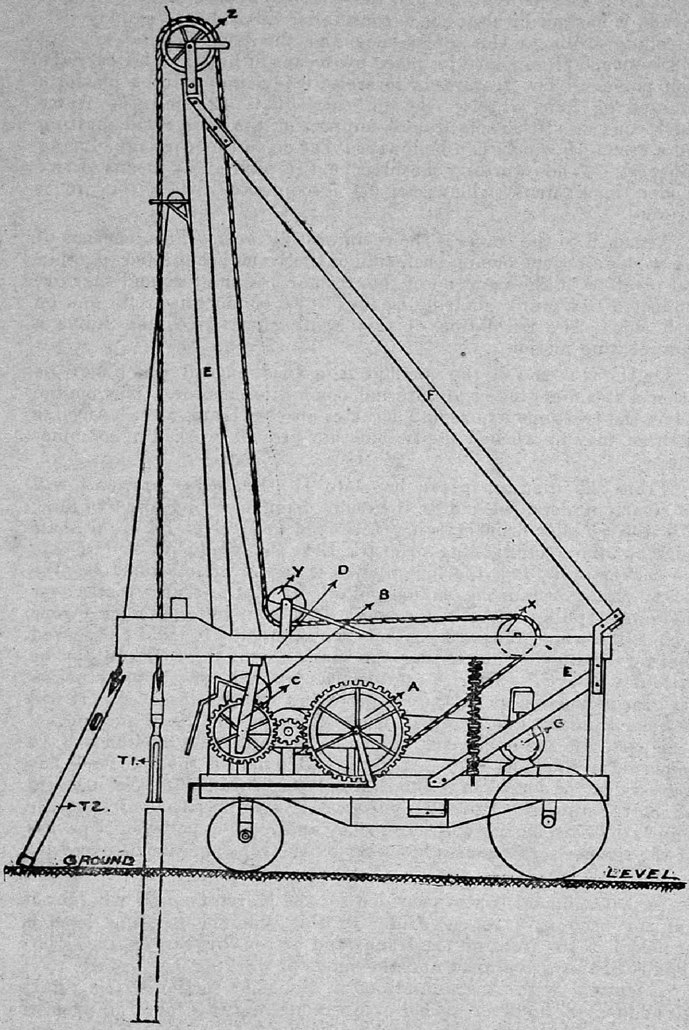
PLATE I.



When the drill is used for percussive drilling, the tool is attached direct to the rope without the intervention of lengthening rods and is lowered on to the working face. Four or five coolies then hang on to the rope between the wynch and the pulley and by jerking it up and down impart the necessary percussive motion to the tool.

Power drills: Percussion Type.—The standard percussion drill used in this department is of the Keystone pattern and is illustrated in plate II. It consists essentially of a carriage, frame, power-driven

PLATE II.



winding drum and a reciprocating arm. The carriage may be either of the traction or of the non-traction type. With the former, the drill is moved by its own power : with the latter it has to be dragged. In view of the light nature of the carriage, the very bad ground which drills have to traverse and the difficulty of obtaining competent drivers, it has not hitherto been considered advisable to employ self-propelling drills in this Presidency and the departmental type of drill is moved from place to place by means of bulls. The carriage itself possesses few features of interest : it is merely a light platform mounted on four wheels. To the carriage is attached the frame which consists of two side frames supporting the drums and shafting and a crane jib which can be lowered flat on to the carriage during transport. When working the jib is held in position by means of two wooden back stays which can be disconnected when the jib is lowered.

Attached to the frame is the reciprocating arm. This consists of two wooden beams, one on each side of the frame, connected together and pivotted on the rear end of the frame. At the fore end they are connected to a crank shaft by means of two connecting rods one on each side. The revolution of this crank shaft gives the frame a reciprocating motion.

On the rear end of the carriage is a fixed engine which may be either a steam-engine or an internal combustion motor. This engine drives the two rope drums and actuates also the crank arm. Any one of these may be worked singly, but they are not worked in combination.

From the diagram given in plate II the *modus operandi* will be clearly understood. *A* is the main drum carrying the tool line; *B* is the smaller drum carrying the sand line; *C* is the crank shaft working the reciprocating arm *D*; *E* is the crane jib and *F* are the back stays. The tool line passes from the main drum over the jockey pulley *X* and the motion pulley (*Y*); after that it passes over the crown pulley *Z* on the crane. The rope terminates in a rope socket into which the working tools are screwed. It will be observed that by winding or unwinding the main drum, the tool line can be raised or lowered. To give the tools the up and down motion necessary for percussion work, the reciprocating arm is employed. It will be clear from the diagram that, if the drum is kept fixed and motion is imparted to the reciprocating arm, a reciprocating motion will be imparted to the tools also. At considerable depths the line itself has a good deal of spring in it and beyond a certain point it is usual to attach the rope direct to the reciprocating arm by means of a temper screw, thus dispensing with the jockey and motion pulleys. The use of the temper screw causes less wear on the rope and avoids excessive spring.

An attachment is also provided for the Keystone drill whereby it can be used as a rotary drill. In this case the rotating head is attached to the front of the frame and driven by the engine. The details of this drive head and the mode of working the rotary tools are identical with those described in the next section. The rotary attachment is, however, rather cumbersome and it is found in practice

that there is not much practical advantage in combining the two systems of drilling so that the rotary attachment is not usually employed on a percussion drill.

For depths up to 300 feet, which is the standard adopted in this department, a 12—14 horse-power engine will provide sufficient power to actuate the drill. The tool line consists of a 350 feet length of best manilla rope 6 inches in circumference. The sand line is of manilla rope of similar length. In place of manilla rope, steel rope 2 inches in circumference may be used for the tool line. Steel rope is less flexible than manilla, but it is much stronger and less liable to break and is therefore to be preferred for the tool line which has to stand very heavy strains. For the sand line, manilla rope is preferable as this line is exposed to less severe work and the flexibility of manilla rope offers certain advantages.

Power drills—Rotary Type.—The principle of the rotary drill is entirely different from that of the power drill already described. There are no cleaning tools and only two kinds of working head. In the rotary system of drilling the use of percussion tools is impossible. A special attachment, however, allows of the use of a monkey weight to drive lining pipes. The departmental type of rotary drill is shown diagrammatically in plate III. The illustration shows a motor driven set capable of going to a depth of 300 feet.

The engine drives the main shaft A off which the circulating pump E is driven by means of a small pinion. A belt connects the drum shaft C with the rotating head R. Another pinion on the main shaft drives the spur wheel on the drum shaft C. The spur wheel is connected with the drum through a friction clutch which can be thrown in or out by means of the lever L_1. A band brake also passes round the brake drum. In its normal working position the rope drum is loose on the drum shaft and is held by means of the band brake. When the lever L_1 is moved back, the first part of the motion releases the brake and sets the drum free. If the lever is pulled still further, it causes the clutch to engage and the drum is thereby actuated. By a suitable motion of the lever L_1 the rope can therefore be kept fixed, be allowed to run out or be drawn up. A second lever L^2 attached to the same shaft as the lever L_1 operates the striking gear on the belt B, throwing it on to the loose or fast pulley and thereby driving or stopping the rotating head. T is the tank for circulating water for the engine and is filled by the pump discharge. P_1 P_2 are the wash pipes connected to the swivel head on the boring rods.

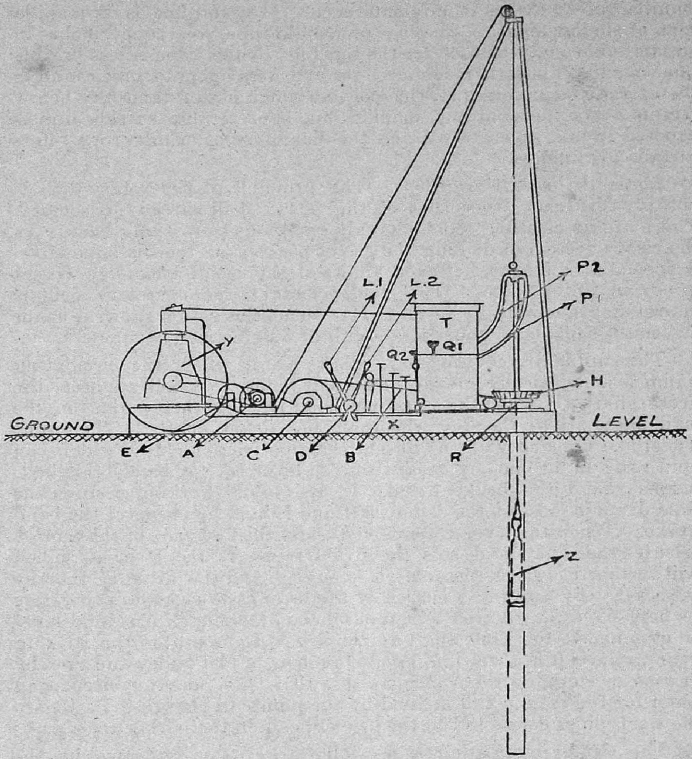
The water circulation is as follows:—Water is drawn by the circulating pump E from the well or any other convenient source and is then pumped back to the distribution valve X the position of which is indicated by the cross, the valve being actually hidden from view. This valve has four outlets—one is a bye-pass to allow any excess of water back into the suction pipe, another is the feed pipe for the tank. A third runs to the wash pipe P_1 and a fourth to the wash pipe P_2. To each of these pipes is attached a feed box Q_1 and Q_2.

The rotating head consists of a fixed foundation ring bolted to the bed plate of the engine on which revolves the rotating plate H driven by a pinion from the shaft actuated by the main belt. In the centre

21 NOV 1918

of this rotating plate there is a shallow depression into which a cast-iron drive plate with a square hole in it is loosely fitted. This plate serves the purpose of giving the necessary rotary motion to the tools.

PLATE III.



To the front of the frame is attached a cross girder which during transport can be removed and laid parallel with the frame. To the cross girder are attached two of the derrick legs, the other two being carried back on the frame as shown. The four legs unite on the crown ring to which is attached also a pulley over which the rope passes.

The *modus operandi* of the drill is as follows:—To the further end of the rod is attached the swivel head carrying the wash pipe terminals. On to the swivel head is screwed a square hollow bar, the section being such as just to pass through the square hole in the drive

plate. Below the square bar are attached hollow lengthening rods of the length required and these terminate in the cutter which will be described later. The string of tools is passed through the drive plate and is lowered until the cutter is in contact with the working face. The rotating head is then put into motion. If the soil is soft and the tooth cutter is used, no water is required. If the soil is hard and the shot head has to be used, water is pumped down the centre of the rods through the wash pipe P_1 from time to time. A small quantity of shot is fed into the feed valve Q_1, and this, travelling down the interior of the lengthening rods finally reaches the working face and acts as an abrasive. When the core is to be removed a charge of coarse gravel is put into the feed valve Q_2, and water is passed through the wash pipe P_2. The gravel on reaching the working face causes the core to snap off. The amount of water in the feed pipe P_1 is to be regulated in such a way as to give a uniform feed of shot to the working face. If more water is required, this is introduced by means of the second wash pipe P_2.

It will be observed that the string of tools is free to sink as the bore progresses until the swivel head reaches the drive plate. When this happens another lengthening bar has to be introduced and for this purpose the string of tools has to be withdrawn, as also when a core is to be removed. To withdraw the tools, the lever A is drawn back and the drum begins to wind up the rope. The square driving rod in rising lifts up the drive plate which lies loose on the rotating head. When the swivel head has reached the crown ring the drum is stopped and the top section of the rods is uncoupled. The swivel head is then lowered and attached to the remaining rods, the process of raising and uncoupling being continued until the whole string has been withdrawn. For depths up to 300 feet, which is the standard depth in this department, a 10—12 horse-power engine will provide sufficient power to actuate the drill. Besides the square driving rod, about 300 feet of lengthening rods and couplings are provided together with the cutting tools which are described in the next chapter.

Sludging consists of washing out the soil by means of a water jet and is applicable only to soft soils. A sludger consists of a string of hollow boring rods terminating in any sort of working tool, as for instance a chisel. To the top of the rods is attached a valve opening upwards. This valve in its normal position is seated on the top of the boring rods and seals them.

The string of boring tools is lowered down the lining pipes which are then filled with water and the string of tools is jumped up and down. When the chisel strikes the bottom a certain amount of water is forced into the pipe and the water level inside the pipe is therefore raised above that outside. The original level is not re-established because the valve seals the top of the boring pipes. At the next stroke more water is forced into the boring pipe and as the action is continued the water inside the pipe continues to rise until it finally issues from the valve on the top mixed with sludge. The action is automatic and continuous and provided the difference in level between the water in the borehole and the valve on the sludger is not too great, progress is quite rapid in soft soils. The equipment,

moreover, is very simple. All that is required is a winch and derrick: a boring tool with a certain length of hollow boring rods attached to it and the sludging valve to screw on to the top of the boring rods. The ordinary apparatus for the driving of lining pipes must also be provided. The whole equipment is light and portable and, where the soil is suitable, the method of sludging has much to recommend it. Unfortunately it cannot be used in hard rock and since in the Madras Presidency, some hard rock has to be dealt with in almost every boring, the sludger is not altogether suited to local conditions.

CHAPTER VI.

USE OF DRILLS.

When a site has been selected, the next operation is to prove the presence of water by a boring. The various types of boring appliances have been described in the previous chapter. The class of plant employed in any particular case will be determined chiefly by the depth to which it is proposed to bore and the character of the strata to be passed through.

For very deep boreholes power drills of the percussion type are exclusively employed. Rotary drills are in many respects preferable to percussion drills; but when the depth of boring exceeds a certain figure the proper centring and rotation of the boring rods—at least in India—becomes a matter of so much difficulty that it scarcely pays to try rotary boring to a depth of beyond, say 400 to 600 feet, unless it is absolutely necessary to obtain a 'core.' Beyond the depth mentioned also, the ordinary semi-portable rigs become unsuitable and regular steel towers from 40 to 80 feet high (according to the depth to be bored) must be employed.

If shallower bores are contemplated the semi-portable power plants described in detail in the previous chapter are the most useful, and either type, percussion or rotary may be employed at option, but in general the rotary type is to be preferred for two reasons. It yields a 'core' which the percussion drill does not and it introduces less danger of loss of tools. The worst that usually happens with a rotary drill is that the drill rod snaps and as the broken portion is usually fairly loose in the borehole it can in most cases be removed without difficulty. In the percussion drill the tools not infrequently jam hard and if they are not loosed with the utmost care and judgment the rope snaps. The difficulty of recovering a string of tools that has jammed is clearly much greater than that of fishing out a section of rod that has merely twisted off.

Even these semi-portable power plants are bulky and expensive to transport and when borings are shallow it is cheaper to employ hand boring tools. In the experience of this department, hand boring tools are efficient and economical for depths up to 100 feet in soft or medium soil and this depth has been fixed arbitrarily as the limit to which hand boring is ordinarily to be confined. Up to 100 feet no

serious mechanical difficulties are encountered though in really hard rock the progress is so slow that it is doubtful if hand boring pays for depths of more than 50 feet in such circumstances. Since however the boring sets belonging to the Department of Industries are leased out on daily hire, the hirer very soon finds out for himself when it pays him to stop hand boring in hard rock. On the other hand in soft or medium soils he may have reached the limit fixed without striking water and may be desirous of continuing the boring. Below a depth of 100 feet there is some risk of losing lining pipes during extraction but otherwise serious mechanical difficulties do not arise until a depth of about 150 feet is reached. Hence, subject to the payment of a deposit to cover the value of the lining pipes in the event of loss, hand boring is permitted in special cases up to 150 feet, but this point is the absolute limit. If water has not then been reached and the lessee wishes to continue the boring all that he can do is to start another one with a power drill. The abandonment of the boring is necessary for other reasons also. The standard size of bore adopted for use with hand-boring sets in the Department of Industries (4″) cannot conveniently be carried to any greater depth. This question of size is dealt with later.

Sludgers are not at present employed in the Department of Industries. As they can be used only in soft soil their field is too limited for general use, though a sludging attachment may be an advantage if used in connexion with a power set. Hand boring is so cheaply done that it scarcely pays to add to the weight of the equipment by the addition of a sludger when, in view of the shallowness of the borings, such an attachment can at best save only a couple of days work and will in many cases be absolutely useless.

We thus see that borings can be divided into three groups. When the depth to be bored is 100 feet or less—or, in exceptional cases when it is less than 150 feet—hand boring is effective and is by far the cheapest method to adopt. Hand boring is a combination of the rotary and percussion systems. Between 100 and 400—600 feet, power must be employed and the choice lies between the rotary and percussion systems, the advantages and disadvantages of the two systems being very nearly equal. Beyond 400—600 feet the percussion system is by far the cheapest and rotary drilling would only be used when it is absolutely necessary to obtain cores as, for instance, in prospecting work.

It is clear that, with power drilling just as much as with hand drilling, some arbitrary limit must be set on the depth to which a given plant may work. The greater the depth, the more massive the machine must be and the greater the power required to drive it. The departmental power drills have been standardized to work to a depth of 350 feet normally but this depth may be exceeded by 50 per cent in special cases and on the same conditions as those attaching to the use of hand drills beyond their normal depth of 100 feet.

Power drills to work to a greater depth have not yet been provided as there is not at present any demand for them.

It will be observed that the selection of a plant depends on the depth to be bored. The individual starting a boring does not, however,

usually hold any pre-conceived ideas on the subject of depth; he wants to find water, that is all. The question of depth he prefers to leave an open one to be determined by the indications furnished by the boring as it progresses. Unfortunately it is impossible to deal with the boring problem in this manner for two reasons—not only does the class of tool employed differ according to the depth to which it is proposed to bore but the size of borehole is different also.

A hand-boring set, as we have seen, will normally drill up to about 100 feet. Beyond this depth—or 150 feet at most—it is unsuitable. If this depth is to be exceeded, a power drill must be employed. Since the principal difference in cost between hand and power drilling lies in the difference in transport charges, the time for erection, etc., it follows that, if a power drill is to be used after all, it is much cheaper to employ it in the first instance rather than to begin with a hand-boring. So also since the type of power drill required for depths beyond say 500 feet is different from that employed for shallow depths it is much cheaper, if the intention is to exceed 500 feet, to begin with the more powerful set than to change over when that depth has been attained.

Further, there is the question of size of bore to be considered. Boreholes usually have to be lined with lining pipes, at least for part of their depth. These pipes have to be driven down as the boring proceeds and the friction increases rapidly as the depth increases. It is impossible without risk of damage to drive a pipe beyond a certain point and what has to be done when this point is reached is to introduce a smaller pipe inside the original one and go on sinking until this pipe, in its turn, also jams.

The smallest size of pipe that can conveniently be worked with is the 4-inch size and as the cost of lining pipes, of labour, of machine hire and everything else increases rapidly with increase of size, the size of a borehole—at least when sunk for exploratory purposes—is kept down to the minimum. Now a 4-inch pipe can conveniently be driven 100—or in special cases 150—feet without damage, but beyond this depth there is serious risk of buckling. For hand-boring tools a 4-inch pipe suffices, but with power drills going to greater depths a larger size must be employed to begin with. For a 300-feet bore, the initial size should be at least 6 inches; when a borehole is to be taken over 500 feet, the top section should be at least 8 inches in diameter.

There are other reasons why a reserve of size is necessary with deeper boreholes as will be clear from the following explanation. When a boring is made in hard soil such as rock, no special protection is required, but in friable soil some sort of lining has to be put down in order to prevent the bore from caving in. The size of a borehole is the size of the finished hole and, in rock or hard soil, where it requires no lining, the hole is bored to its correct diameter straight away. If, however, the soil is soft and requires lining, it is evident that the size of the hole made must be rather larger than the finished size so as to allow of the insertion of the lining pipes.

When a borehole is started, we can use a tool rather larger in size than the diameter of the finished bore so as to allow the necessary clearance for the pipes. But once the lining pipes have been inserted, the size of the tools is limited to that of the finished borehole;

otherwise, the tools will not pass through the pipe. After the first few feet, therefore, it is impossible to cut the bore larger than its finished diameter and the lining pipes have to cut their own clearance as they are driven. This cutting is done by attaching a cutting shoe to the bottom of the pipe and in soft soils the pipe can be sunk without much difficulty. When, however, hard rock is met with, the pipe can no longer be driven in this manner nor is it essential then to continue it. So long as hard rock continues, there is no difficulty in going on with the boring. It is when a soft stratum is again encountered after passing through a hard one that trouble arises. It is clear that we cannot insert any further sections of the original diameter of pipe since they would not pass through the pipe already put down nor through the hole cut in the rock. If the soft stratum will not stand, the only thing that can be done is to insert, inside the original lining pipe, another lining pipe of smaller diameter and to carry this down until hard rock is again met with. The pipe can then be no further driven and we have to cut into the solid rock as before. If subsequently another soft stratum is met with, we have to introduce a still smaller size, and so on and so on, until at last we reach the minimum size that we can work with.

It is not impossible, though extremely difficult, to enlarge holes in rock so as to admit the passage of lining pipes, but it rarely pays to do this, except in cases where the hard stratum is comparatively thin and is immediately followed by another soft one.

It has already been explained why for mechanical reasons a single size of pipe cannot be sunk to an indefinite depth and the explanations above furnished show why this usually cannot be done for physical reasons also. Up to the limits of a hand-boring set changes of strata such as those indicated are not likely to occur, but beyond that depth, it is extremely probable that they will be met with and an ample reserve of size should therefore be allowed at the start.

It will be evident from what has been said that a change in the size of a lining pipe enormously increases the amount of pipe to be carried, and changes become more frequent the greater the depth to be bored. The cost of transporting all these pipes is a considerable item in the total cost of deep well boring. For a 4-inch boring up to a maximum of say 150 feet we have to carry only 150 feet of lining pipe. If the bore is to be 300 feet deep with one break, we have to carry say 150 feet of 6-inch pipe and 300 feet of 4-inch. If the bore is to be 500 feet deep, we shall probably have to allow two breaks. It is therefore necessary to provide something like 200 feet of 8-inch, 3—400 of 6-inch and 500 feet of 4-inch pipe.

Experience shows that it is not economical to try and enlarge a borehole. It has been done, of course, but with the class of labour available in South India, the trouble is so great and the results usually so unsatisfactory that, if a borehole is too small, it is much cheaper to abandon it and start afresh with a larger one. Just as the whole cost of transporting and rigging up a drill is wasted if subsequently a larger one has to be employed, so also is the whole cost of boring wasted if subsequently a larger one is found necessary. It is thus imperative at the very outset to determine exactly to what maximum depth the bore is to be carried. If water is discovered at

a less depth, a certain amount of money has been wasted in transporting a plant and putting down a bore larger than subsequent events show to be necessary. On the other hand, the loss is infinitely greater if too small a bore is put down to begin with, for in this case the whole amount spent is wasted.

CHAPTER VII.

BORING TOOLS.

The tools used in boring may be divided into six classes :—

(1) Boring rods and means of attaching them.
(2) Rotary tools.
(3) Percussion tools.
(4) Cleaning tools.
(5) Fishing tools.
(6) Pipes and appliances for pipe driving.

The rotary and percussion tools are the actual working tools. The cleaning tools are those employed to remove loose stuff, debris, etc., that have collected in the borehole. Fishing tools are those used for removing lost or broken tools from the borehole.

The shape and size of the tools depend on the type of drill with which they are used and to some extent also on individual fancy. "Specials" may be multiplied indefinitely, but in the following paragraphs only those tools which have been found of general use will be described.

Hand-boring tools.—The boring rig has already been explained: The tools ordinarily used are as follows :—

(1) Boring rods : swivel rod, boring rod, hand dogs, lifting dogs.
(2) Rotary tools : worm auger, clay auger, rod tillers, rhymer.
(3) Percussion tools : flat chisel, T chisel.
(4) Cleaning tools : sand shell.
(5) Fishing tools : spiral worm.
(6) Pipes and appliances for pipe driving : lining pipes, pipe head, shoe, pipe wrench, pipe clamps, spring dart.

In hand-boring drills, the rope usually terminates in a hook illustrated in Fig. 2-a, plate IV, to which the string of tools is attached. The hook is an ordinary hook provided with a cylindrical sleeve which slides over the tongue and when in its lowest position prevents the latter from opening during work. The rope may also terminate in a rope socket as illustrated in Fig. 1, plate IV, the string of tools in this case being secured to the rope socket by screwing. The rope socket is permanently fixed to the rope and if both forms of attachment are required, it is usual to have two ropes.

Boring rods.—The tool directly connected to the hook is the *swivel rod* illustrated in Fig. 2, plate IV. This rod is about 4 feet long and 1½ inches square. The *swivel head* allows the tools to rotate freely without twisting the rope. When the rotary method of drilling is to be employed, *boring rods*, as illustrated in Fig. 3, plate IV, are attached to the swivel rod as required and to the bottom of these

boring rods is attached the working tool. When the percussion method is used, the working tool may be attached directly to the swivel rod but as the hook cannot pass into the borehole, boring rods have usually to be interposed and it is more convenient to employ the rope socket to which the working tool can be directly attached.

Boring rods are 10 feet long and 1½ inches in diameter, but two short lengths, one 6 feet and one 4 feet long are usually supplied with each set to make up odd lengths. Swivel rods terminate in a female thread. Boring rods have a male thread at one end and a female thread at the other. All threads are standard, being 1½ inches

PLATE IV.

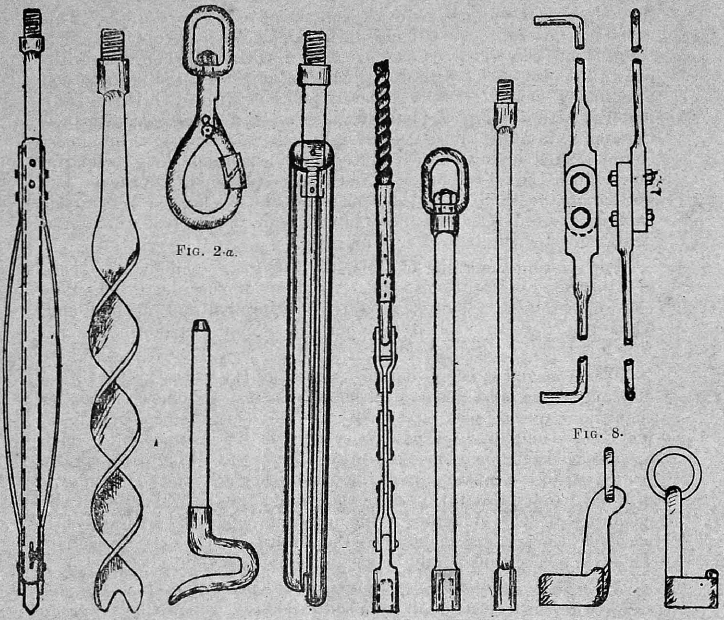


FIG. 9. FIG. 6. FIG. 4. FIG. 7. FIG. 1. FIG. 2. FIG. 3. FIG. 5.

in diameter and screwed with standard threads 6 to an inch. The greatest care is necessary to turn the shoulders and threads absolutely true. Otherwise the rods are likely to become unscrewed during work.

Boring rods and the tools attached thereto are screwed and unscrewed by means of *hand dogs*, illustrated in Fig. 4, plate IV. These tools require no particular description as their use is obvious. They serve the place of a spanner and are supplied in pairs.

When a string of tools is being removed from a borehole, it has to be unscrewed section by section and to support the lower section whilst the upper one is being unscrewed, a *lifting dog* is employed. This tool is illustrated in Fig. 5, plate IV. The lifting dog is passed round the boring rod just below the shoulder and the string of tools is then lowered until the dog rests on the top of the lining pipe, thereby supporting the lower section of tools. When the top section has been removed, the rod is lowered and the hook passed through the ring on the lifting dog. The second section is now lifted and another dog put under the shoulder of a lower rod. The string is again slightly lowered to allow the dog to rest on the pipe. The next section is now removed and the process continued until the whole string has been withdrawn.

Rotary tools.—Fig. 6, plate IV, is a sketch of the *worm auger*. This is the most useful tool in stiff clay formations. Its use is obvious; it is screwed into clay like a corkscrew into a cork and when it is withdrawn the clay comes with it. If such an auger is used in loose soil of a loamy character, it will merely pull out without bringing any material with it. Fig. 7, plate IV, illustrates a *clay auger* which is the appropriate tool to use in such light soils. It consists of an almost complete shell having a narrow slit ¾ inch wide running along its length. One edge of the slit is sharpened and projects beyond the other. The bottom of the shell is shaped somewhat like a gimlet. When this shell is revolved, it bores its way into the soil, the excavated material being collected inside it.

For rotating the string of tools, *rod tillers* are employed. These are illustrated in Fig. 8, plate IV. As shown in the illustration, they consist merely of a pair of rods terminating in a flat at one end. These two flats are bolted together from opposite sides of a rod which is thereby rigidly held.

When boring is being done by means of the worm auger or the clay auger, the hole is sometimes not true or may be somewhat smaller than the required size. To rectify these defects, the *rhymer*, Fig. 9, plate IV, is employed. The rhymer consists of a central bar to which are attached four bent springs. At the top, the springs are rigidly connected to the centre bar; at the bottom they are attached by means of a nut passing through a slot in the springs thus allowing them to be compressed. One side of each spring is sharpened and as the tool is revolved, the springs scrape away the material to the correct section. This tool can of course only be used on comparatively soft soil

Percussion tools.—As already explained, percussion tools may be screwed to the swivel rod or attached direct to a rope socket. When working at considerable depths it is more convenient to use the rope socket because this leaves the main rope free for use with cleaning tools and cleaning can therefore be carried on without constantly changing the tool on the rope.

The standard percussion tool is the *flat chisel* illustrated in Fig. 1, plate V, and this tool is used for any rock which is too hard for the clay auger to operate in. In very hard rock the standard chisel may not be heavy enough and special heavy chisels are sometimes employed. These are described under the head "Specials" as they are only

occasionally required and do not form part of the standard equipment of a set.

Flat chisels must be kept turning when in use, otherwise they form an irregular hole. Even with care, such irregularity cannot always

PLATE V.

FIG. 10.

FIG. 1.

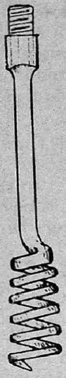


FIG. 4.

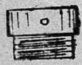


FIG. 7.

FIG. 6.

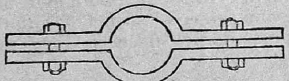


FIG. 9.

FIG. 5.

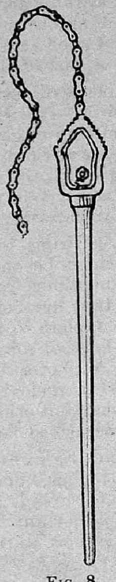


FIG. 8.

FIG. 3.

FIG. 2.

be avoided and when it occurs, it is rectified by the use of the "*T" chisel* as illustrated in Fig. 2, plate V. The T chisel is exactly the same as the flat chisel except that a pair of lugs or fins are welded on to one side. These fins have a curvature corresponding with that of the borehole, and as the T chisel is worked (being rotated at every stroke) it trues up the borehole. The T chisel is sometimes used in very soft clay in place of the rhymer.

Cleaning tools.—The clay auger and worm auger remove the material excavated but chisels do not; they merely pulverize the rock which has to be removed by other means. For the purpose of removing debris or water from the borehole, a *sand shell* or *water shell* is used. The tools are practically identical, except that the upper end

of a sand shell terminates in a screw and that of a water shell in an eye. There is also a difference in the valve. A sand shell is intended to lift detrital matter. This enters through the valve at the bottom and when the shell is lifted, the material closes the valve and also seals any small cracks. A stiffened leather valve is quite good enough in this case. A water shell, on the other hand, is intended to remove clear water from the borehole and so the valve has to be tight and a good deal heavier, otherwise all the water escapes. A sand shell can always be used as a water shell by plugging the valve with clay and allowing the water to enter at the top. This arrangement is not quite as good as a water shell, because in the latter, water can enter at both ends. But as it is usually unnecessary to draw clean water from a boring, the sand shell arrangement is good enough and water shells are not issued as a part of the standard equipment of a set.

The sand shell is illustrated in Fig. 3, plate V, in which the valve is also shown. It will be observed that the bottom of the shell terminates in a cutting edge.

The sand shell is worked by dropping it to the bottom of the boring and then jerking it up and down a few times. At the end of each stroke a certain amount of material enters the valve and when the shell is full, it is withdrawn.

Fishing tools.—Owing to carelessness in the tightening of the joints, tools sometimes become unscrewed and fall to the bottom of the borehole. Sometimes rods break or the tools jam and some part gives way whilst they are being extracted. To recover lost tools, the *spiral worm*, Fig. 4, plate V, is often useful. As will be observed from the illustration, this tool consists of a closely wound worm which when revolved over the top of a broken rod frequently catches hold and enables the tool to be removed. The spiral worm is the only fishing tool supplied to sets, but other tools are kept in reserve for use when required and are described later.

When a borehole requires lining, *lining pipes* are used. In hand sets these are all 4 inches diameter and about 8 feet long. Both ends are specially screwed 11 threads to the inch and the ends turned off square. Accuracy is most important for if the pipes do not fit dead they are very likely to come loose during driving.

To one end of the pipe a socket is rivetted and the standard pipe with socket is shown in Fig. 5, plate V.

In order to enable a pipe to descend easily and correctly it is fitted with a pipe shoe as illustrated in Fig 6, plate V. To protect the screw at the top end, especially when the pipe is being driven, a *pipe head* is screwed on to the top section. The pipe head is shown in Fig. 7, plate V.

Whenever possible, pipes should be sunk by screwing and not driving. To give them the necessary rotary motion *pipe wrenches* of the common pattern are employed. These are illustrated in Fig. 8, plate V, and are supplied in pairs.

For the purpose of supporting the pipes during withdrawal and to prevent their slipping back, a pair of pipe clamps are used as shown in Fig. 9, plate V. They consist merely of two pieces of flat iron, bent to shape and bolted together across the barrel of the pipe.

As in driving, so also in withdrawing pipes, a rotary motion is to be preferred. But sometimes the pipes stick and then they are either jerked up by means of the clamps or else lifted by the *Spring dart*, illustrated in Fig 10, plate V.

The spring dart is a stout bar having two spring catches, one on each side. To lift pipes the dart is lowered down the borehole. When they pass the shoe, the catches expand under the pipe and this enables it to be lifted by the dart as it is gradually withdrawn.

PLATE VI.

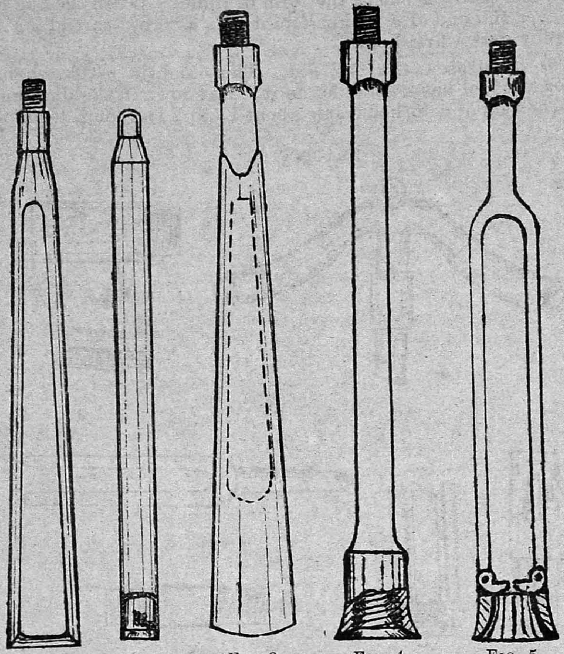


FIG. 1. FIG. 2. FIG. 3. FIG. 4. FIG. 5.

In addition to the above tools, a number of "Specials" are kept in reserve. These are only rarely required and are therefore not issued to sets but may be obtained on application to the store. The "Specials," are illustrated in plate VI and some of them have already been described, as for instance, the *heavy chisel*, Fig. 1, and the *water shell*, Fig. 2.

The only other tools really required are extra fishing tools and a couple of *jacks* to deal with refractory pipes. Jacks are not illustrated as they are too well known. Fig. 3 represents a horn socket. This consists of a conical shell, like an extinguisher, about 3 to 4 feet

long. Down the side of the conical casing there is a long narrow longitudinal slit extending over the length of the pipe but not reaching the bottom end. This slit gives the casing a certain amount of spring and when the horn socket is driven violently on to the top of the tool, the casing grips the end of the tool and enables it to be withdrawn.

Fig. 4 illustrates a *screw bell box* which is used for picking up fractured tools which cannot be gripped by the spiral worm or the horn socket. The screw bell box is similar to a boring rod and is about 2 feet in length. It terminates in a conical bell on the inside of which a taper screw is cut in the form of a die. When the bell box is rotated over the end of a broken tool it cuts a screw thread on to it and thereby gets a firm hold.

Fig. 5 illustrates the *bell box.* This tool is used when the broken or lost tool has a shoulder on it. As shown in the diagram, the bell box consists of a forked frame about 1½ to 2 feet long, terminating

PLATE VII.

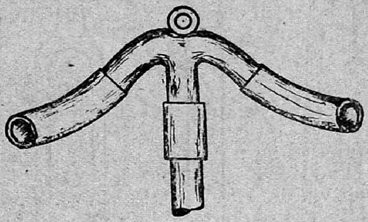


FIG. 1.

FIG. 8.

FIG. 3.

FIG. 6.

FIG. 7.

FIG. 4.

FIG. 5.

FIG. 2.

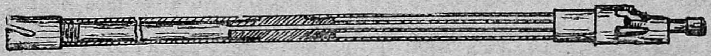


FIG. 9.

in a collar passing easily inside the borehole. To the upper end of the collar are attached a series of spring teeth which release upwards but not downwards. As the bell box is lowered over the end of a rod, the teeth are pressed up and so allow of the passage of the rod. When the shoulder has been passed, the teeth drop down again and as the bell box is withdrawn they engage the tool below the shoulder and thereby enable it to be lifted.

Power boring tools—Rotary.—One of the principal advantages of the rotary drill is that it requires practically no tools. Such tools as are required are shown in plate VII.

The boring rod equipment consists of a *swivel head* corresponding to the swivel rod in the hand drill. This is illustrated in Fig. 1. The two pipe terminals on each side are connected with the wash pipes and to the central boss are attached the boring rods.

The boring rods shown in Fig. 2 are hollow, 8 to 10 feet long and 1¼ inch diameter. The ends are swelled and screwed with a square thread four to the inch. The *sockets* are shown in Fig. 3.

In place of hand dogs, *wrenches* are used for tightening up the rods. These may be of any common pattern and are not illustrated.

In place of lifting dogs, a common *fork* as shown in Fig. 4 is used for supporting the pipes during extraction.

The cutting head, Fig. 9, consists of a shell, head and cutter. The head is shown separately in Fig. 5 and consists merely of a cylindrical plug about 6 inches long and slightly less than the diameter of the borehole, screwed on to the end of the boring rod. The outside of the plug is screwed with right and left hand threads, right hand above and left hand below. Over the upper screw passes the shell, Fig. 6, which is merely a cylindrical pipe, sufficiently small to pass easily inside the borehole. It may be made to any convenient length but 3 to 4 feet is the usual dimension. The function of this pipe is merely to catch fine sedimentary matter that may be passing upwards and prevent it from again descending and causing unnecessary wear to the tool. To the lower screw is screwed a similar pipe which again may be any convenient length. The usual dimension is 6 feet. The object of this pipe is to accommodate the core. If a 6 feet pipe is used, drilling may be continued for 6 feet without lifting the string of tools; if a 4 feet pipe is used, the string has to be lifted every 4 feet, etc. To the bottom of the pipe is screwed the *cutter*, shown on a larger scale in Figs. 7 and 8.

Fig. 7 illustrates the *tooth cutter* which is used in soft soil. When the tool is revolved, the teeth cut away the material in an annular form leaving a core which rises inside the core shell. Fig. 8 illustrates the *shot head* which is used when hard material has to be drilled. The water passing down the hollow boring rods and through the calyx head and carrying with it the charge of shot descends down the inside of the core shell and the shot finally passes down the slot in the cutter and works its way on to the working face of the cutting edge, that is between the bottom face of the cutter and the rock. The cutter bearing on the shot causes it to abrade the hard rock and in this way, as before, an annular space is removed leaving an interior core to rise inside core shell.

No percussion tools or cleaning tools are used with rotary drills. The only fishing tool is a *spiral bell box* similar to that already described.

The equipment for pipes and pipe driving is also similar to that for hand boring tools.

No "Specials" are provided.

PLATE VIII.

FIG. 1.

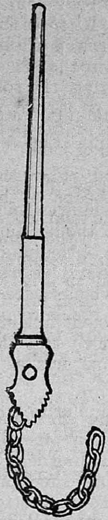


FIG. 2.

FIG. 3.

FIG. 4.

FIG. 5.

FIG. 6.

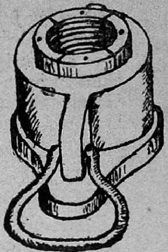


FIG. 8.

FIG. 7.

Power boring tools—Percussion.—Although no regular boring rods are used in the percussion drill, a certain number of bars are usually attached to the rope above the working tool in order to give it weight. The *boring bar* or *drill stem* illustrated in Fig. 1, plate VIII, is a bar 12 to 14 feet long and 3 to 4 inches in diameter. Such a bar is almost invariably used. Sometimes the boring bar by itself is not sufficiently heavy and additional weight is provided by means of *sinker bars* which are exactly identical with boring bars except as regards length. They may be of any desired length but 8 feet is the usual length. Sinker bars are usually unnecessary.

To tighten up tools, heavy *pipe wrenches* as illustrated in Fig. 2, plate VIII, are employed.

Sometimes a special rotary attachment is provided, the tools for which are entirely similar to those described under the heading Rotary Tools.

The percussion tools consist of different kinds of chisels. Fig. 3, plate VIII, illustrates the spudding bit, which is a chisel used for starting a boring. It is rather larger than the size of the borehole and thus allows of sufficient clearance for the lining pipes. It can obviously be used only until the first lining pipe is inserted. The diameter of the tool is larger than that of the boring pipe and so it cannot pass through the pipe when once put down.

For working in sand, the best tool to use is the *sand* pump, illustrated in Fig. 4, plate VIII. This pump consists of a heavy outer casing inside which fits a loose plunger, the rope being attached to the plunger rod. When the shell is lowered to the bottom of the borehole, the plunger falls to the bottom of the shell. When the rope is lifted, the shell remains in position but the plunger rises drawing the soft material with it. When the plunger reaches the end of its stroke, it begins to lift the shell also. The valve at the bottom of the shell then comes into operation and prevents the material running back.

When the soil is too stiff to be removed by the sand pump, the *mud socket* is used. In soft soils it is usual to bore by means of the mud socket which is illustrated in Fig. 5, plate VIII. The mud socket is merely a substantial form of sand shell and it is used in the same way. When the mud socket fails to make any further impression on the soil, the rock chisel is used. This chisel is illustrated in Fig. 6, plate VIII. It is very similar to the rock chisel used in hand boring except that it is very much more massive. When a sufficient amount of material has been broken down, the chisel is withdrawn and the debris removed by means of the mud socket, which thus acts as a cleaning tool also.

The equipment for pipes and pipe driving is exactly similar to that for hand boring drills except that it is on a more massive scale. Two or three special attachments are, however, sometimes provided, namely, the *pipe pulling head* and the *pipe knocking head*. These are illustrated in Figs. 7 and 8, plate VIII.

The pipe pulling head consists of a massive forging with a large circular hole rather greater than the diameter of the pipe. The hole is conical in shape. Into it a number of tapering pieces fit. The forging is placed over the pipe tapering side up and the packing pieces are then dropped into position. It is evident that as the forging is drawn upwards the packing pieces tend to grip the pipe and so enable the pipe to be lifted.

The pipe knocking head consists of a cast iron pipe head screwed on to the top of the pipe. Through the centre of the head a loose rod passes with a shoulder at the bottom end, the upper end of the rod being attached to the rope. When the rope is lowered, the rod passes freely through the head. When the rope is raised, the rod is drawn up and the shoulder coming in contact with the head gives it a smart blow thereby tending to lift the pipe.

A considerable number of "Specials" is required with a percussion drill. These are illustrated in plate IX. Fig. 1 represents a pair of steel jars. Jars are usually attached to the string of tools above the boring bar and serve to intensify the blow given by the tool. The jars consist of two links which intermesh and have a travel of about 4 inches. The use of the jars gives the working tools a certain amount of freedom.

PLATE IX.

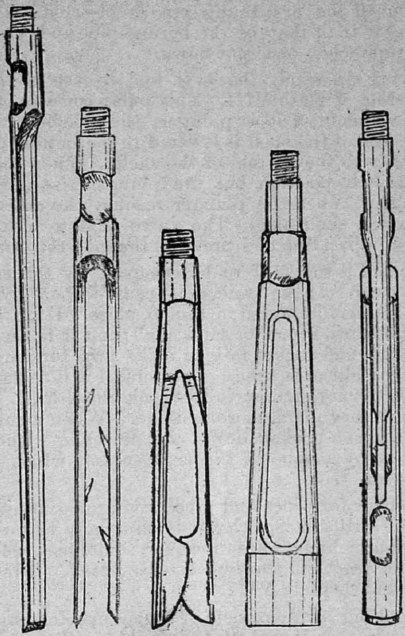


FIG. 5. FIG. 4. FIG. 3. FIG. 2. FIG. 1.

The *horn socket* is similar to the tool used in hand boring sets and is not illustrated.

The *slip socket* takes the place of the bell box used with hand tools. As shown in the illustration, Fig. 2, the slip socket consists of a forked frame terminating in a ring tapering on the inside. But in the place of teeth a spring, like a pair of sugar tongs is inserted. When pressed upwards the spring expands and allows the free passage of the broken tool into the bell box. When the bell box is drawn upwards, the spring is drawn downwards against the taper of the ring and seizes the tool firmly.

The *rope shear* shown in Fig. 3, is employed to cut off broken pieces of rope and the *rope spear* shown in Fig. 4, is used in order to engage broken pieces of rope. The use of these two tools will be obvious. The *spud*, illustrated in Fig. 5, is used for loosening tools that have jammed. It consists of an arm set excentrically on the socket and curved to the radius of the borehole. This tool is worked between the tool that has jammed and the sides of the borehole and often serves to free it.

There is also a considerable number of other tools illustrated in catalogues that are sometimes used, but those above described have been found to meet all practical requirements, at least in Madras.

CHAPTER VIII.

PRACTICAL HINTS ON BORING.

See that your equipment is complete and in good condition before you start work.

The surface soil will usually be soft. To start a borehole in soft soil, begin by digging a hole with a mahmooty about a foot deep and pour in a bucket of water. Now work the worm auger for three or four feet or as far—not exceeding eight feet—as the borehole will stand unsupported. Then take the pipe shoe, see the cutting edge is clean, and screw it tight on to a section of the lining pipe. To the top of the pipe attach the pipehead and then lower it into the borehole. Great care must be taken to see that it is vertical since errors in verticality lead to serious trouble as the depth of the borehole increases.

When the first lining pipe has been lowered almost to its socket, remove the pipehead, screw on another section of pipe (after having carefully wiped the screw thread) and see that the pipe is well home in the socket. If there is any slack, return the worn pipe or socket *at once* to headquarters for repairs. Remember that using worn pipes or boring pipes loose in the sockets will mean that they will part during withdrawal and the pipes will thereby be lost.

The first few sections of pipe will probably sink by their own weight. Nevertheless, the pipehead should always be attached to the top section, if only for the purpose of protecting the thread.

If working with a hand drill, use the clay auger or clay shell: if with a rotary power drill, use the tooth cutter and if with a percussion drill, use the mud socket. If the soil is very sandy, a sand shell or sand pump may be used. It is absolutely necessary to carry on the lining pipe as the bore deepens. Maistris have a habit of boring five or six feet in advance of the pipe before driving it further. This is one of the most prolific causes of loss of tools: the shoulder of the tool catches the cutting edge of the pipe and something breaks.

Pipes may be driven either by percussion or rotation. In the former method, a monkey weight is attached to the rope and dropped on the pipehead : in the latter, the pipe is gripped by means of two pipe wrenches and turned in the ordinary way. During the turning process, it is either loaded or lightly tapped to make it sink. The driving of pipes by means of heavy weights is objectionable and should be avoided whenever possible, as it causes strain at the joints and tends to make them loose.

In loose soils lining is imperative : in solid granite it is impossible, but there exist a large number of intermediate kinds of soil or rock in which lining is optional. Whether lining is done or not depends entirely on circumstances. Once a lining pipe has been stopped and further lining becomes necessary when the boring has been deepened a smaller size of pipe has to be utilised. If therefore there is a prospect of lining again being required further down it is better to carry down the original pipe if possible ; otherwise, stop lining as soon as the stratum worked in permits of this.

When soil becomes too stiff for the tools mentioned, it is necessary to change over to rock chisels or shot cutters. In using rock chisels the important thing to remember is to keep the chisels sharp and true and to keep them turning.

A gauge ring is supplied with every set and the chisel must fit the ring as shown in Fig. 5. In elevation the sides must project slightly beyond the body of the chisel as shown in the figure. But by far the most important point is the angle of the cutting face. This angle depends entirely on the character of the rock to be cut, but for each kind of rock there is an angle that gives the best results. If the angle is too blunt, the chisel merely pulverises the rock ; if too acute, the chisel blunts itself without making much impression on the rock. The correct angle must be found by experience and adhered to ; it is somewhere about 60° as shown in Fig. 6.

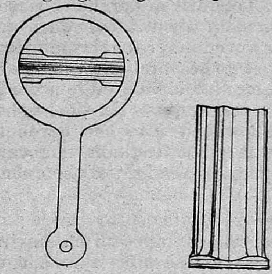


Fig. 5.

When jumping with a chisel, the rope is adjusted in such a way as to make the chisel strike a smart blow. If the rope is too short, the chisel never strikes the rock at all ; if it is too long, the blow is struck before the chisel has gained its full impetus and is correspondingly feeble. The correct adjustment of the rope is a most important matter which again has to be determined by experience or " feel."

Fig. 6.

When a chisel is being used, it is most important to keep altering the orientation of the blows, otherwise an elliptical hole is formed. Such a hole gives a great deal of trouble as tools will constantly be jamming. It is difficult to remedy an elliptical hole once it has been formed ; one may

try and true it up with a T chisel, but the best thing is to exercise caution in the first instance and avoid forming elliptical holes.

When a certain amount of material has been broken down it has to be removed by means of the sandshell. It expedites matters a great deal if two lines are used, one for the sandshell and the other for the chisel, for in this way a constant exchange of tools is avoided.

The sandshell is used by dropping it down the borehole and jumping it up and down several times. The material enters the valve at the bottom and when the shell is withdrawn, it is tapped up and the material run out from the top. Some maistris waste a great deal of time by keeping the sandshell jumping up and down for a quarter of an hour at a time. Whatever material the sandshell will take it will pick up in a few minutes, after which it should at once be withdrawn. Other maistris only jump it once or twice and then withdraw it which means that it has to be put down the bore an excessive number of times to clear the debris. This also means a waste of time.

After the sandshell is emptied, it should be properly cleaned out with clear water to clear the valve and remove adherent matter. If this is not done, the valve often fails to close next time and the material runs out again, whilst to leave adherent matter in the shell clearly reduces its capacity.

When a shot cutter is used it is important to see that the shot feed is correct. This can be judged by looking at the wash water. If solid shot is found, it means that the feed is excessive: if insufficient shot is fed, the cutter does not cut. The shape of the bottom edge of the cutter is also a thing that requires careful attention. When newly ground, the bottom of the cutter is dead square: the wear of the shot tends to make it round. With a rounded cutter the shot tends to jam and the cutter should therefore be trimmed at frequent intervals. At moderate depths it is usual to allow the whole weight of the string of tools to rest on the cutter but if it is excessive, it may be eased by taking part of the weight on the rope.

With rotary drilling it is still more important than with percussive drilling to see that the hole is drilled dead vertical. If it is out of truth, the rods get a tremendous amount of whip on them at moderate depths.

Tools may often get stuck, and as a last resort, jacks may have to be employed to try and withdraw them. But jacks should never be used except when other methods have failed.

To begin with, an attempt should be made to loosen the tool by getting eight or twelve men to jerk on the rope between the winch and the pulley. If this is not sufficient and the string of tools projects beyond the top of the borehole, long wooden beams may be attached to the boring rods and an attempt made to rotate and loosen the rods thereby. If this method is not effective, a lever arrangement may be tried. A wooden beam is attached firmly to the string of tools or the rope and laid across a fulcrum as near as possible to the borehole. A number of men jump up and down on the long arm of the lever and in this way the rod may be loosened. It will be observed that in all the foregoing cases the power is not a dead pull

but a series of jerks, the latter being a much more effective method of loosening the tool than the former. If jacks have to be employed, the string of tools or the rod should be continually tapped as power is applied and, whenever possible, the tool should be rotated. Sometimes boring tools may be recovered in this way: if not, it usually happens that the rope or string of tools gives way somewhere and then we have to fish for the parts.

If tools have merely become unscrewed, it is generally possible to pick them up by lowering fresh rods and screwing these on. If the tool does not remain vertically in the borehole, but fall sideways, the rods may fail to grip. In this case, the spiral worm may first be tried if the drill employed permits of the use of rotational tools. The spiral worm can usually be made to engage the top of the lost tool, which may then be withdrawn. The spiral worm does not damage the tool recovered. If the spiral worm fails, the screw bell box may be used. As explained in a previous chapter, this is merely a tap which screws itself on to the tool it engages and thereby withdraws it. This method of fishing obviously damages the tool recovered, but is very often successful.

The tools above described can only be used on drills with a rotary attachment. The horn socket and bell box can be used on either rotary or percussion drills. The *modus operandi* of the last mentioned tools has already been fully explained. Which particular tool is used in any particular case is largely a question of choice. Sometimes one tool may succeed when others fail, but there is no universal rule and all that can be done is to go on trying till successful.

All the aforementioned fishing tools can be used with hand boring sets, but are not at present supplied to each set by the department. They are kept in reserve for use as required. With rotary power drills, only the screw bell box is usually employed. With percussion power drills, the horn socket is used together with a modification of the bell box, termed the slip socket. In addition, rope spears and rope shears, as described in a previous chapter, are usually kept in reserve. The use of these tools is obvious. The spud, as already described, is also provided. A spud is jumped up and down round the tool that has got stuck and, in this way, often serves to ease the tool. Spuds must not be mistaken for spudding bits and they are not to be used as cutting tools or rhymers as some maistries are inclined to do.

The process of pipe driving has already been explained. A few words may be said on the question of pipe pulling. When a borehole is complete, it is often necessary—as for instance if a well is to be sunk or if the bore has proved a failure—to withdraw the pipes. To begin with, the same process is followed as previously adopted for sinking, namely, turning the pipes, only, instead of weighting them, a rope is attached to the top so as to give them an upward pull. So long as pipes can be withdrawn by this means—however slowly—it is desirable to persist therewith. Sometimes, however, pipes stick. As already explained in connexion with ordinary tools, the jack should only be used as a last resource, anything of the nature of a dead pull tending to strip the threads at the joints and to leave large

sections of the pipe behind. A very useful tool in connexion with the withdrawal of pipes is the spring dart, which has been described in Chapter VII. When the pipes stick, the spring dart is dropped down the borehole and, expanding below the pipe shoe, enables the pipes to be lifted bodily, unless the teeth or the rope give way, which sometimes happens. With large rotary drills, the pipe pulling or knocking head may be employed. The pulling head gives a dead pull. The knocking head gives a series of sharp taps and is therefore to be preferred.

GENERAL HINTS.

With rotary drills, the tools must always be rotated clockwise, otherwise they will come unscrewed.

Do not work in a dry borehole.

Always examine your machine and tools before starting, especially ropes. See that rope sockets are securely rivetted and all valves, screws, etc., clean and tight.

Never use a blunt tool : if you do, you will get a jam.

Even if no rotation is required, a slight pressure in the direction of rotation should be maintained in order to keep the tools tight.

Boring rods.—See that all screws are clean before screwing up and screw well home. Unless joints are absolutely tight, they will come unscrewed and you run a risk of losing your tool. If the screws get damaged or show signs of wear, send the rods back for repair at once.

Lining pipes.—Examine your threads carefully and reject pipes with damaged threads or bad indentations. See that the pipes are a good fit in the sockets and that they can be screwed in until they butt up against each other. Remember that a bad pipe joint will certainly mean trouble.

Chisels.—See that the end is properly sharpened to the proper angle and is properly tempered. Keep the chisel rotating. A new chisel will cut bigger than an old one and when starting a new chisel, go easy to avoid jam.

Get your blow right by adjusting the rope. When at rest, the chisel should not touch the working face : the spring in the rope will enable it to deliver the necessary blow. If the rope is too long or too short, you lose half the effect of the blow.

Sandshells.—In the case of fine running sand, the shell should be worked continuously. If it is allowed to rest, the sand may settle round it and cause it to seize.

Wash out your sandshell very carefully every time you draw it out. This may seem a small matter, but the particles left behind, if the shell is not properly washed, are liable to get into valves and so interfere with the working of the shell.

The sandshell may be used for testing supplies when these are small.

In particular, remember to maintain a daily log of work done recording the total depth bored, the character of the strata and the water levels.

CHAPTER IX.

THE COST OF BORING.

In the following chapter are given such figures of cost as are available. So far as they relate to the cost of plant they may be regarded as substantially correct, but it is clear that the cost of boring will vary enormously with individual conditions and figures relating to working costs must accordingly be looked upon as purely approximate.

As regards plant, hand boring sets of the departmental pattern (excluding derricks) are offered by Messrs. Burn & Co., Calcutta, for Rs. 1,100 or so. This quotation is for the 4-inch size which is the standard size in the department. The equipment includes the standard tools, namely :—

	NO.	RS.
1. Lining pipes of 8′	12	360
2. Rods, 10′	9	162
3. Rod of 6′	1	17
4. Rod of 4′	1	14
5. Swivel rod	1	16
6. Hand dogs	2	15
7 Lifting dogs	2	25
8. Pipe wrenches	2	40
9. Pipe clamp	1	20
10. Rod tiller	1	20
11. Rhymer	1	20
12. Spring dart	1	20
13. Spiral worm	1	15
14. Worm Auger	1	30
15. Clay Auger	1	35
16. T. Chisel	1	45
17. Flat Chisel	1	25
18. Sandshell, $2\frac{1}{2}''$	1	25
19. Wynch with two handles	1	125
20. Manilla rope, $4\frac{3}{4}$	1	35
21. Spring hook	1	20
22. Single sheaved pulley	1	12
23. Derrick posts	set of 3 purchased locally.	
24. Monkey spanner		5
25. Head and shoe for lining pipes ...	pair	21
26. Crowbars, 3″	2	3

Specials may be obtained at extra cost as required.

	RS.		RS.
Horn sockets ...	10	Chisels ...	35
Bell boxes ...	48	Water shells ...	25

The cost of a power drilling plant depends on the depth to which it is required to bore. The size standardized in the Department of Industries is intended to bore from 100′ to 350′ as a maximum. For this size, a 10-h.p. engine is sufficient with a rotary drill, and a 14-h.p. with a percussion drill. The rotary type employed in this department is of a special departmental design and is not on the market.

The percussion drill used in this department is that manufactured by the Keystone Drill Company, Beaver Falls, Pennsylvania. It is

25793

the No. 3 non-traction type and costs about Rs. 3,750 landed, excluding engine and tools. The machine has been described in a previous chapter and the price includes rope, derricks, belting and usual accessories.

The tools required are numerous. The standard equipment is as follows: and prices are given for 6-inch and 4-inch sizes :—

	6-inch.		4-inch.
	RS.		RS.
Rope socket	40		35
Temper screw	100		80
Drill stem	155		115
Steel jars	240		200
Spudding bit	80		50
Rock bit, 2 at 138	276	2 at 75	150
Mud socket, 2 at 100	200	2 at 70	140

The following accessories are also needed :—

	6-inch.		4-inch.
	RS.		RS.
Heavy tool wrenches 2 at 45 ...	90	2 at 40	80
Pipe heads and shoes	25		12
Driving clamp with wrench ...	66		46
Pipe clamps 2 at 12-8-0	25	2 at 6	12
Pipe wrenches 2 at 36	72	2 at 25	50
Gauges	5		3½

Sand pumps and water shells are optional, they cost Rs. 40 and Rs. 30 and Rs. 25 and Rs. 18 respectively in the two sizes.

Fishing tools are as follows :—

	6-inch.	4-inch.
	RS.	RS.
Slips socket	120	110
Horn socket	75	65
Rope spur	100	80
Rope shear	65	50

Only the first two form part of sets: the last two are 'extras' Other 'extras' are :—

	6-inch.	4-inch.
	RS.	RS.
Sinker bars	100	75
Pipe pulling and knocking heads and pipe pulling ring.	350	...

Lining pipes and sockets are dealt with later.

The departmental plant will cost about Rs. 3,500 and this price includes the swivel head, boring head and shell, square driving rod and 300 feet boring rod with necessary couplings together with two jacks and the usual tools. Boring rods are supplied by the British Mannesman Company and cost Rs. 10 each in 10 feet lengths. Couplings, supplied by the same firm, cost Rs. 2 each.

The only working tools required are cutters which are of two kinds, toothed, for soft rock and slotted for hard rock. Both are made from solid drawn tube supplied by the Mannesman Company, and each cutter costs about Rs. 7-8-0 to make.

The only accessories required are a pair of wrenches at Rs. 10 for screwing and unscrewing the rods and a pair of holding dogs at Rs. 8.

To the above prices must be added the cost of the engines. The type of engine used will be determined by circumstances. The horse-power required has already been stated (10—14). The cost can be ascertained from any maker's catalogue. In the department, two stroke oil-engines are used for the rotary drill. These cost (10 h.p.) Rs. 2,250 each. For driving the percussion drill both steam and oil are used, steam being probably the more satisfactory. The cost of steam plant of the required size (14 h.p. engine, boiler and fittings) is between Rs. 2,500 and Rs. 3,000 according to make.

Power drills of larger size have not yet been purchased by the department as the demand at present for borings above 350 feet is not sufficient to warrant the investment. Roughly speaking, a 600 feet set would cost about Rs. 5,500 and a thousand feet set Rs. 6,400 complete.

Every set is also to be furnished with a certain amount of lining pipe. As already explained, the lining pipes used by the department are of two standard sizes, four inches for depths less than 100 feet and six inches and four inches for depths up to 300 feet. Eight-inch pipes are also used to some extent. Two makes of pipes are used: steam pipe by Messrs. Stewart and Lloyd and solid drawn pipe by the British Mannesman Company. These are bought in random lengths and screwed departmentally. Sockets are made from thick hollow tubing. Pipes and sockets may be obtained from Messrs. Burn & Co., Calcutta, at the following approximate rates :—

		8-inch.	6-inch.	4-inch.
Pipes and sockets ...	Rs.	7-0-0	5-0-0	4-12-0

From the above figures an idea of the initial outlay on boring plant can be formed.

For purposes of calculating standing charges the following approximate figures including equipment of cost may be assumed :—

	Rs.
Hand boring set	1,200
Rotary drill	3,500
Percussion drill, No. 1 size	7,000

The cost of drilling may be divided into two parts, viz., fixed charges which have to be met whether the drill is working or not, and working charges which are only incurred when the drill is doing useful work. Thus the charge for the use of a drill consists of two parts, one based on the number of days that the drill is available; the other on the number of days that the drill is actually at work. If, for instance, the drill is available for 300 days in the year and the fixed charges amount to Rs. 600, the proportion of fixed charge is rupees two per working day. If running cost amount to rupee one per day, working charges are rupee one and the total charge is rupees three per working day.

It is usual to reckon about 300 working days per year but every working day is not a working day for a drill. A considerable time is often spent on rail transport. For a part of the year a drill is

under repair and during some months, i.e., during the cultivation and rainy seasons ryots often refuse to have borings done. For these and similar reasons a hand drill loses about eighty days in the year and a power drill about 100.

But there are further losses. The time of local transit from one place to another must be subtracted, also days when on account of rain, shortage of coolies, the set has to remain idle as well as the time taken to set up and take down the plant and also, when a boring is a failure, the time taken to withdraw boring pipes. All these periods vary greatly according to local conditions. For stoppages due to rain, breakdown, etc., 15 per cent on working time is a low figure, for the withdrawal of lining pipes approximately 10 per cent on working time may be allowed. Incidental delays thus amount to about 25 per cent of the working time. The time lost in local transit is very variable. If borings are close together one day will be enough: if some distance apart possibly a week—exclusive of rail transport. Local transit time is equivalent on the average to about three days' idleness in the case of handboring tools and ten days in the case of power drills. For setting up and dismantling a set, getting carts, etc., an allowance of five days may be made. Thus for x actual working days, the total number of days during which the drill is employed on the work will not be x, but x + 25 per cent of x + transit and setting up time, i.e., $\frac{5}{4}x + 8$ days for hand drills and $\frac{5}{4}x + 15$ days for power drills.

We have seen that the number of days annually for which the drills are available for work amount to about 220 and 200, respectively, in the case of hand and power drills. On account of the time losses above indicated this period is still further reduced. In fixing the charge for a drill we may allow for these losses either by increasing the fixed charges proportionately or else by calculating them on more days than those actually worked. The latter system is preferable as it leads to a fairer distribution of charge. According to this system, which is adopted here, the charge for x working days will be the working charges for x days + fixed charges for $\frac{5}{4}x + 8$ days in the case of hand drills and $\frac{5}{4}x + 15$ days in the case of power drills (excluding transport charges).

We may now calculate what these charges are. Fixed charges include interest, depreciation and staff charges. Repair and maintenance are charged to working charges.

Interest is to be allowed at 4 per cent. On handboring plant no depreciation is allowed as the component parts have constantly to be renewed and maintenance charges therefore cover depreciation.

The average pay and travelling allowance of a boring maistri is about Rs. 33 per mensem = Rs. 396 per annum. Interest is Rs. 48. So that the annual standing charge is Rs. 444. Figuring on 220 working days in the year, the average daily charge may be placed at Rs. 2.

With the rotary drill 4 per cent depreciation may be allowed on the frame, pump, pipes, etc., 8 per cent on the engine, gears, etc.; the total is Rs. 440.

The staff consists of three men, drawing in the aggregate, including travelling allowance, about Rs. 100 per mensem. The total annual standing charge is therefore Rs. 1,640. Figuring on 200 working days, the average daily standing charge may be fixed at Rs. 8 roughly.

With the percussion drill 4 per cent depreciation may be allowed on the frame, 8 per cent on engine and working parts. As in the case of hand boring sets no depreciation is allowed on tools as these have constantly to be renewed.

The cost of staff is much the same as in the previous case and interest and depreciation are slightly higher. Rs. 9 per day is a fair figure.

As regards working charges, the cost of repairs has first to be estimated. It is found from figures that the average cost of maintenance with departmental plant amounts to Rs. 200 annually, this figure including also tools lost. The repairs and renewals to boring rods, pipes, cutters, etc., in the case of a power rotary drill will, with careful handling, not exceed Rs. 500 on a 200-day year and so Rs. 2–8–0 per working day may be allowed. The cost of renewals for power percussion drills is heavy and extremely variable. In any day a careless driver may lose Rs. 300 worth of tools and the deviation from the average in individual cases may be very large. As a mean, Rs. 3 per working day is a reasonable allowance, though on the low side. So far as labour is concerned a hand boring set requires about six coolies, a rotary drill three, and a percussion drill four. Allowing an average of As. 5–6 a day for them, the cost is Rs. 2, Re. 1 and Rs. 1–6–0, respectively. The power drills also require fuel, oil and stores.

The oil engines on the rotary drills consume about 8 gallons of liquid fuel in a 10-hour day, costing anything between Rs. 2 and Rs. 4. They will also use 8 annas worth of oil and say 4 annas worth of stores. As an average we may take the cost at Rs. 4 per day.

In the percussion drills kerosene engines are being used as there is scarcely room for the more substantial liquid fuel engines on the frame. The fuel costs with kerosene are about double those with liquid fuel, but the power is slightly greater and we may assume the cost to be Rs. 8 per day.

A steam engine will consume nearly half a ton of coal daily, or about $1\frac{1}{2}$ tons of wood. The cost of wood and coal vary tremendously in different districts, but in the districts where the steam engine is employed coal costs about Rs. 20 a ton, so that the working cost will be about Rs. 10 per day.

As a rough average we may suppose the fuel costs on rotary drills to be Rs. 4–8–0 and on percussion drills Rs. 9 per day.

The working costs per day are therefore as follows :—

	Repairs.	Labour.	Fuel and stores.	Total.
	RS.	RS.	RS.	RS.
Hand drill	1	2	...	3
Rotary drill	$2\frac{1}{2}$	1	$4\frac{1}{2}$	8
Percussion drill	3	$1\frac{1}{8}$	9	$13\frac{1}{8}$

These charges may be summarised as follows :—

	Fixed charge. RS.	Working charge. RS.
Hand drill	2	3
Rotary drill	8	8
Percussion drill	9	13½

To calculate actual cost for x days effective work we have to add x times the working charge to $(\frac{5}{4}x + 8)$ times the fixed charge (for hand drills) and $(\frac{5}{4}x + 15)$ times the fixed charge for a power drill.

Departmental charges are of course no criterion of costs since the work is being done at a considerable loss. Under the departmental system a flat daily charge is made to cover all costs except labour and fuel which are borne by the ryot. These form part of the working charge and amount to Rs. 2 for hand drills, Rs. 5-8-0 for rotary, and Rs. 10-8-0 for percussion power drills. The departmental charges are Rs. 2 for hand drills and Rs. 6 for power drills: rather more than half of what they should be.

From the above figures, however, a fairly good estimate can be made of what drilling may be expected to cost when we know what progress can be expected per working day. The depth bored through in a day will vary tremendously according to local conditions, but the appended table will give some idea of the magnitude of the quantities involved.

Work that can be done per day in feet.

Depth.	Hand.					Power.			
	Very soft.	Soft.	Medium.	Hard.	Very hard.	Soft.	Medium.	Hard.	Very hard.
0—25	20	16	8	1·75	·5	20	16	10	5·0
25—50	15	12	6	1·35	·35	18	14	9	4·5
50—75	10	8	4	1·00	·25	16	12	8	4·0
75—100	6	4	2	·75	·2	14	10	7	3·5
100—150	...	...	...	...	...	12	8	6	3·0
150—200	...	...	...	...	...	10	6	5	2·5
200—300	...	...	...		...	8	4	4	2·0

For instance, a rotary power drill boring through 20 feet soft soil, 20 feet medium and 20 feet hard soil will take the following time :—

	Feet per day.	Feet.	Time.
0—20 Soft	20	20	1 day.
20—40 Medium	14	20	1·5 days.
40—60 Hard	9—8	20	2·3 „
			4·8 days, say, 5 days.

Working charges 5 × 8 = Rs. 40.

Fixed charge for $\frac{5}{4} \times 5 + 15$ = say 21 days at Rs. 8 = Rs. 168.

Total Rs. 208 = Rs. 3·5 per foot.

The same for hand drills.

	Feet per day.	Feet.	Time.
0–20 Soft	16	20	1·25 days.
20—40 Medium	6	20	3·33 ,,
40–60 Hard	5	20	4·00 ,,
			8·58 days, say, 9 days.

Working charges 9 × 3 = Rs. 27.
Fixed charges for $\frac{5}{4} \times 9 + 8 = 19$ days at Rs. 2 = Rs. 38.
Total Rs. 65.

In such soil power drilling clearly does not pay.

Take another example: 50 feet medium, 50 feet hard, 50 feet very hard.

With a rotary drill the time works out at about 27 days.
The working charges are 27 × 8 = Rs. 216.
The fixed charges are $\frac{5}{4} \times 27 + 15 = 49$ days at Rs. 8 = Rs. 392.
Total Rs. 600 odd.

In the hand drill the time is about 330 days.
The working charges are 330 × 3 = Rs. 990.
The fixed charges are $\frac{5}{4} \times 330 + 8 = 420$ days at Rs. 2 = Rs. 840.
Here the cost of hand boring becomes prohibitive.

The above figures must not be regarded as anything but purely approximate and rough, but they give some idea of what borings cost and indicate, to some extent, under what circumstances power and hand boring are most economical. In American drilling contracts the rate charged is usually between Rs. 3 and Rs. 5 per foot.

To these charges must be added the cost of lining pipes which are supplied by the Department at the reduced rate of Rs. 2 per foot for 4-inch pipes and Rs. 3 for 6-inch pipes. The cost of local transport must also be added. This comes to about Rs. 7-8-0 for hand drills and Rs. 50 for power drills.

The charges for boring now being levied by the Department amount to about half the cost above indicated.

CHAPTER X.

THE FLOW OF WATER IN SAND.

In a previous chapter it has been observed that there is reason to suppose underground water to be normally in a state of rest and on this assumption it has been argued that the total amount of water that can be obtained from a well during any one season is a fixed quantity. The question of the motion of underground water lies at the root of the well problem and is of such importance that it is proposed in the present chapter to deal with it at length.

So far as the water-supply in wells is concerned, the problem we have to investigate is of a two-fold character. To begin with we must determine the character of underground flow. But before we can

work out any mathematical expression for the flow of water into a well, we must also ascertain the laws of the flow of water in an infinite homogeneous medium. The character and laws of flow will accordingly first be dealt with.

It may be as well to explain at the very outset that so far, no satisfactory formula for infiltration into wells has been worked out. Various empirical formulæ have, from time to time, been put forward but, as will be shown in this chapter, they are mostly based on inaccurate physical assumptions. It may be argued that the evaluation of a mathematical expression for the flow into a well will not prove of very much practical value since variations in local conditions which cannot be expressed by formulæ might be expected to lead to such large variations in results as to make calculation valueless. Observation, however, goes to show that saturated beds of considerable uniformity exist over large areas and in such areas it seems probable that a much closer agreement can be secured between theoretical and actual results than would at first sight appear possible. In any case, theoretical results, even if they cannot be practically applied, are always of great value in indicating what are the factors entering into the problem and in showing to what extent each factor is likely to influence results. In the present chapter such general information as is available regarding underground flow has been collected and analysed.

(1) *Character of underground flow.*—When water is pumped from a well located in a saturated homogeneous water-bearing stratum, it is known that the water level in the well falls and that, on the cessation of pumping, it gradually regains a position somewhere near its former level. To account for the recovery of a well, two theories have been put forward. According to the first, the water in the saturated stratum is supposed to be in motion and the recovery is therefore regarded as due to the passage of a fresh supply of water into the exhausted area. On the second theory, the water is supposed to be at rest and the recovery is regarded as due to a local readjustment of water levels. The first theory is called the 'flow' theory and the second the 'exhaustion' theory.

It is known that the effect of pumping is to exhaust the water in the stratum to the extent of a figure of revolution in shape approximating to an inverted cone and termed the 'cone of exhaustion.' The surface of the cone is termed the 'saturation curve.' The base of this cone lies on the original saturation plane, its apex being the reduced water level in the well. According to the first theory, the cone is filled up by the access of flowing water. According to the second theory, there is no actual replenishment, all that happens being that the cone gradually flattens out and approaches a shape corresponding to a minimum potential for the new saturation surface.

The former theory implies that wells will furnish an inexhaustible supply: the latter that the supply to be obtained is limited. These theories cannot both be true. In different places different conditions may possibly prevail: in Madras—which is the area under consideration—the conditions of the problem are represented by large underground strata of water-bearing sand of limited thickness—say 20 to 50 feet—usually lying over or between other impervious strata

From these water-bearing beds a considerable amount of water is annually abstracted by pumping for irrigation purposes.

A certain proportion of this water may return to the stratum by infiltration and a certain percentage of the local rainfall may reach the stratum in a similar manner. But the supplies thus derived will be small and quite insufficient to account for the observed replenishment. Hence not only in the first, but also in the second theory must some sort of flow be postulated. In the latter case it is supposed that replenishment takes place not continuously, but in waves, so to speak, during definite seasons of the year: as for instance during the monsoon when the numerous—usually dry—water courses which intersect the area run full. At such periods the replenishment of wells may follow some irregular law, but this is a matter of no practical moment since at that time there is little demand for water and questions of adequacy of supply do not arise. It is during the dry season that it is essential to know what a well will yield and during these periods the second theory asserts that there is no flow, or rather that the flow is so slow as not appreciably to influence the manner in which a well recovers its level.

Both theories are in the main mere hypotheses, but there exists a certain amount of evidence to show that the second or 'exhaustion theory' is the more correct of the two. If, for instance, replenishment takes place by lateral flow as postulated by the first or 'flow' theory, the cone of exhaustion will be distorted in the direction of flow. General observations show no indication of any distortion and though in practice the effect of this distortion might be somewhat veiled by other disturbing influences and a negative result does not therefore constitute definite proof against the flow theory, yet it is sufficient to throw doubts on the validity of that theory.

There are also other observed facts which it is difficult to reconcile with the flow theory. It is found that the water levels in wells close to each other fluctuate sympathetically. If one well is being pumped out, the water level in the other falls. It is evident that on the flow theory a series of wells situated at right angles to one another, should affect each other very little, if at all, whereas if the series follows the line of flow the first well should be affected very little by the rest but should affect these a good deal. No such difference has been observed with wells situated along and normal to the direction in which water, if it flowed at all, would naturally be expected to flow.

Further, since the water obtainable from a well on the flow theory would be proportionate to its sectional area normal to the direction of flow, this theory would lead to the inference that the supply in a well could be indefinitely increased by an indefinite increase in section normal to the direction of flow. This inference is absolutely opposed to experience which shows that the rate of increase of supply decreases rapidly with increase of section.

Again it is to be concluded from the flow theory that the supply in a well will be unaffected if not actually increased by the construction of a retaining wall on the side away from the direction of flow.

The expedient was actually tried in connexion with the Madura water-works scheme and was found to have just the opposite-effect to that anticipated.

Certain experiments undertaken by Mr. Chatterton also throw grave doubt on the flow theory. Observations on spring channels in the Palar river showed that water did not flow through sand if the slope of the water table was more than 1 in 250.

"From most sandy rivers the ryots in the hot weather obtain water for irrigation by means of what are known as spring channels. The spring channel is a ditch dug in a dry river-bed and made to run upstream at a slope considerably less than that of the river-bed itself. At first it runs through dry sand till it reaches the level at which the water is standing in the river. As excavation is continued upstream, the bed of the spring channel falls below the water-level and water from the surrounding sand trickles into the channel and flows downward. At some point in its downward flow the water in the channel begins to rise above the level of the water in the river, and thence onward, it flows back into the sand and would continue so to flow, were it not that, after a time, the sand becomes saturated with water and the flow from above passes on, till finally it reaches the river bank, through which it passes in an open cut. Now, if water flowed readily or even very slowly through sand, so great is the length of these spring channels that it is certain the water which drained into the upper section of the channel would disappear by percolation in the lower section, but as a matter of fact it does not do so. Cross sections taken on the Palar river furnish proof on this point. Where the spring channel was in deep cutting and water was percolating into the channel, the slope of the water surface towards the channel was 1 in 250. Similarly in cross sections lower down where the water level in the channel was above that of the river, the slope was about 1 in 250 away from the channel. That is to say, the water in the lower half of the spring channel is carried upon an enbankment and this embankment is formed because when the slopes reach a gradient 1 in 250, the water is unable to move through the sand. This may be taken therefore as conclusive evidence that water does not move down the sandy beds of rivers unless the slope of the sand is greater than that of the hydraulic gradient necessary to make the water move."

It appears legitimate therefore to accept as a working hypothesis the assumption that the replenishment of a well—at least under the conditions prevailing in the water-bearing sand beds of Southern India—is due to a local readjustment of water-levels and not the motion of water as a whole.

Laws of flow in a saturated medium.

Singularly little work, either analytical or experimental, has been done in connexion with the motion of liquid in an infinite homogeneous medium and the literature on the subject is scanty in the extreme.

In but few instances have the laws of flow been considered independently: in most cases the laws enunciated represent merely

hypotheses put forward for the purpose of affording a basis of calculation for the discharge from a well.

The following equation, stated by Debanne is typical of a large number of others :—

$$\frac{h}{l} = K\,(v)$$

where h = head. K = Constant.
l = length of path. v = velocity.

This equation is no doubt perfectly sound : indeed Colonel Clibborn's elaborate experiments made in 1896 prove (if any proof is required) that in a pipe filled with sand, the hydraulic gradient is constant. But the equation only applies to constrained undimensional flow which does not represent the conditions of the well problem.

Hubbe examines the case of the passage of water through sand under hydraulic pressure. He assumes that flow takes place along infinitely fine tubes and starting from Hagen's equation for flow in pipes he obtains the formula

$$C = 66\,d\,\frac{h}{l(H + l)^{\frac{1}{4}}}$$

where C = Constant.
d = diameter of grains in millimeters.
H = initial head of water.
h = head during flow.

The quantity of water flowing per square foot of section per hour is

$$Q = 2{,}178\ d\,\frac{h}{(H + l)^{\frac{1}{4}}}$$

Viollet in attempting to obtain an expression for the discharge from artesian wells develops an equation of flow which has no physical meaning. Hilton assumes that the velocity is proportionate to h, h in this case being the depression in the well : Close makes the same assumption. Hubbard and Kiersted make the same assumption as Debanne. Western works on the infinitely small pipe hypothesis.

Hazen, introducing a temperature term adopted from Poisseuille's ratio, obtains an empyrical formula for the flow of water in sand.

$$V = 3\ C_m\ d_m{}^2 \left(\frac{t + 10}{60}\right)\frac{h}{l}.$$

C_m, d_m being mean values and d being expressed in 1/100ths of an inch.

V in this case is the equivalent velocity, or velocity of a column of water having the same sectional area as that through which percolation occurs.

This formula has been experimentally verified and for values of $d_m = \cdot 65$ to 8 1/100ths of an inch ; C_m (ft. per 24 hours) is fairly constant, having a mean value of about 1,100.

Flow of water into a well.

Most of the above investigators go on to consider the well problem also.

Debanne and Hibbard and Kiersted using the equation :

$$\frac{h}{l} \text{ i.e. } \frac{dy}{dx} = K(v)$$

integrate cylindrical elements round the vertical axis of the well. This is equivalent to the assumption that water approaches the well radially in such manner that the total quantity flowing across each elementary cylinder (whose axis is the centre line of the well) is the same, and that the velocity of the whole body of water at any point is a simple function of the slope of the water table at that point. They further introduce, into their general formula, the symbol h being the total thickness of the water bearing stratum in the place of d (the depth of the well). This substitution is clearly legitimate only in a particular case, namely, when the well reaches to the bottom of the water bearing stratum.

The hypothesis of radial flow is obviously still less tenable than that of lateral flow, which has already been discussed, and the assumption that the velocity of the whole body of water at any point is a simple function of the slope of the saturation curve at that point likewise has no physical justification. The relation may hold good for the layers immediately adjoining the saturation curve, but there is nothing to warrant the extension of this relation to the whole body of water.

Hilton and Close work on much the same lines. The former assumes the velocity to be a function of the slope of the saturation curve (s) : S, the limiting value of s seems to be regarded as a constant in any particular case. On Hilton's theory, the quantity

$$D + S \sqrt{\frac{h}{2}} \text{ (} D \text{ being diameter of well)}$$

represents the diameter of the base of the cone of exhaustion.

To obtain an expression for the discharge he multiplies the area of percolation by the velocity. As the area of percolation he takes the basal area of the cone of exhaustion. The legitimacy of such an assumption is open to doubt. His final equation is—

$$Q = \left(\frac{D}{2} S \sqrt{h} + \frac{S^2}{4} h \right) \pi \times \sqrt{h} \times \text{co-efficient.}$$

Close also introduces the symbol S which with him means the 'radius of action' or radius of cone of exhaustion, which quantity he regards as constant and independent of the depression h. This assumption seems contrary to experience Integrating his expression for flow :

$$Q = \sqrt{\frac{h}{s}},$$

over the surface of a cylinder co-axial with the well, he gets the expression—

$$Q = CS^n \left(S + \frac{D}{2} \right) h^{\frac{3}{2}}$$

and finally assigns to h a value of $\frac{1}{5}$.

Western calculates inflow thus: if the area of the well is B sq. ft. the differential equation for flow is—

$$Ah^k + B\frac{dh}{dt} = CD^k$$

when water is rising and there is no pumping—

$$Ah^k + B\frac{dh}{dt} = 0$$

Parker, assuming that V is a function of the slope of the water-table and utilizing Hazen's formula, obtains the expression—

$$Q = \frac{1{\cdot}36C\,(H^2 - h^2)}{\text{Log}\,\frac{R}{r}}$$

where r = radius of the well, h being the depressed water level.

R = radius-vector of the point at which the water level is H, the undepressed level.

Forcheimer, by a somewhat similar analysis, gives the yield of a well as—

$$Q = \frac{1{\cdot}36C\,(H^2 - h^2)}{\text{Log}\,\sqrt{c}\,\frac{2a}{r}}$$

where a is the limiting distance from which the supply is drawn.

Most of these theories seem to be based on erroneous or inadequate theories of flow. Only the last two investigators, for instance, pay any attention to the temperature co-efficient which is one of the most important factors of all. Underlying nearly all the theories is the tacit assumption that the velocity of flow is proportionate to the slope of the saturation curve. Such an assumption is clearly false. Again the equations of flow employed all postulate parallel flow in one direction, conditions which evidently do not prevail in the well problem.

What the motion in a well actually is does not very much matter, so long as we can determine an equivalent motion which satisfies physical conditions and fits in with the system of integration adopted. The character of the equivalent motion to be investigated will depend therefore on the mathematical treatment of the problem and as this has hitherto resisted all attempts at solution on legitimate physical lines it is not evident what kind of motion we have to study: all that can be said is that it is certainly not parallel constrained undimensioned flow.

The formulæ given in this chapter are physically inaccurate and must therefore be accepted with considerable reserve. They are however empyrical and therefore represent fairly correctly the conditions from which they have been derived. As a rough approximation they may serve: in any case they are the only formulæ available, so that they leave no choice.

CHAPTER XI.

ESTIMATION OF SUPPLIES.

As has been explained in a previous chapter, boring is in the first instance to be regarded as work of an exploratory character and the actual measured discharge from a borehole will usually be considerably less than the discharge we should expect from the source of supply when properly developed. What we require to know, for practical purposes, is the 'developed' supply. The process of estimating supplies may therefore be divided into two parts:—

(1) The actual measurement of the discharge from a trial boring.

(2) The calculation of the probable developed supply from the data thus obtained.

The first operation: the measurement of discharge is a purely mechanical one. Two cases occur in practice. Sometimes the water will not rise above the top of the borepipe in which case it has to be pumped from the *borehole.* Sometimes the water overflows the top of the borepipe, as frequently happens when a pipe is sunk at the bottom of a well, or when the supply is artesian. Here we can pump from the well or ground itself. The suction of a pump is limited to about 24 feet and a borepipe is too small to admit a pump. Hence whereas in the latter case we can employ any ordinary pumping appliance for testing purposes we must, in the former, employ some special water lifting device that can be lowered down a borehole. When the discharge is small an ordinary water shell may be used, but for large discharges this is inadequate. In such a case a loose plunger pump may be employed, but probably the best thing to use is a compressed air pump.

This machine is a very simple one consisting essentially of an air compressor and a length of pipe, say 1 inch diameter. This pipe is lowered down the borehole and attached to the discharge pipe of the compressor. Compressed air is then pumped into the borehole and in rising carries the water with it. The efficiency of the machine is low, but that is a matter of little importance in testing. The bottom of the pipe should be as far down the borehole as possible, preferably near the bottom. Such a test will usually determine what the discharge from the boring is, but still leaves us to determine what the developed supply will be.

When we have an open reservoir, such as a well, to pump from, our problem is much simplified as we can employ any sort of pumping contrivance that may be to hand; the larger the better. We can usually manage to secure a double mhote which is about the most convenient appliance for testing purposes.

There are two things to be noted in making a test. The discharge and the rate of depression. When a picotta or any sort of bucket is used the discharge may be approximately estimated by multiplying the capacity of the bucket (which can be calculated easily) by the number of times it is lifted per minute. Similarly the discharge of a reciprocating pump may be determined by multiplying its displacement by the number of strokes per minute. The discharge from a centrifugal pump may be obtained from the characteristic curve when

the speed is known. But the measurement of speed and reading of characteristic curves are usually beyond the capacity of the observer. When compressed air pumps are used, the discharge cannot be calculated and in both the latter cases discharges must usually be found by direct measurement. With a horizontal and fairly uniform discharge an easy and convenient method of estimate is to measure the fall of the jet. This gives the velocity of discharge and, when multiplied by the section of the pipe, gives the volume.

The fall may be measured by holding a rod (levelled by means of a spirit level) across the top of the jet and measuring the fall x, as shown in Fig. 7, corresponding to a standard length y. The relation between the velocity v and the fall x is as follows for standard values of $y = 3''$, $6''$ or $12''$:—

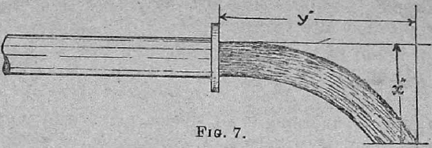


Fig. 7.

When $y = 3''$, the formula is $v^2 x = 12$ (i).
When $y = 6''$, the formula is $v^2 x = 48$ (ii)
When $y = 12''$, the formula is $v^2 x = 192$ (iii).

If, for instance, the diameter of a pipe is 4″ and the fall (x) for $y = 3''$ is found to be 3″, the velocity will be from formula (i) $v^2 = \frac{12}{3} = 4$, i.e., $v = 2$ feet per second, and the discharge will be $\pi r^2 v = \frac{22}{7} \times (\frac{1}{6})^2 \times 2 = \frac{11}{63}$ cubic feet per second, or about 66 gallons per minute.

Another way of measuring discharge and a much more accurate one is by running the discharge into a tank and allowing the water to overflow over a rectangular notch. The discharges for a rectangular notch for each inch breadth of the notch are approximately as follows :—

Depth d.	*Discharge.*
1″	150 *galls. per hour.*
2″	430 "
3″	780 "
4″	1,200 "
5″	1,685 "
6″	2,212 "

This method is more accurate than any of the others but the apparatus requires a good deal of setting up before tests can be made.

When one of the above methods of measuring the discharge has been selected, pumping is started and kept up steadily, the discharge being noted at intervals of say 10 minutes and the fall in the surface of the well at the same interval. Pumping is kept up until the suction pipe is exposed or until a continuation of pumping fails to lower the surface appreciably. When the well or borehole has been pumped as low as possible, pumping is stopped. The rates of recovery and the water level are again noted at the same intervals as before. The dimensions of the well must also be measured. From the foregoing data a fair idea can be formed of the rate at which the well is discharging.

The simplest way of recording observations is by plotting them on a curve to a base of time, the levels being shown as ordinates. Curves of this kind are shown in Figs. 8 and 9.

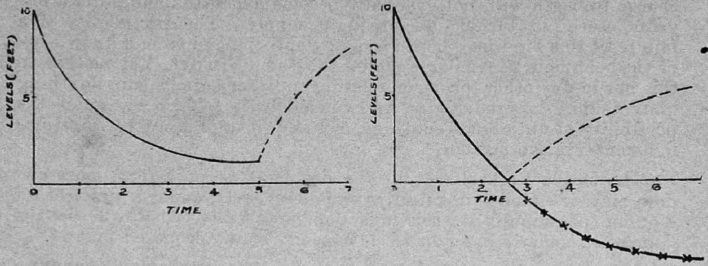


FIG. 8.

The full curve is the falling curve and the broken one the curve of recovery. In Fig. 8 it is evident that the level tends to a position of equilibrium but in Fig. 9 the fall is still marked at the end of the experiment and although by extrapolation we may obtain an equilibrium position as shown by the star lines, the position so obtained may be very much in error and must be treated as merely approximate.

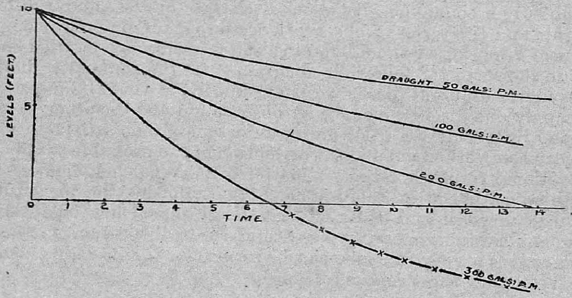


FIG. 9.

These curves furnish a record of the discharge from trial borings and from them the probable developed supply has now to be calculated. The results of observation must however be applied with caution. If, for instance, the supply is merely a surface one (p. 2), it may be adequate during the rainy months but fail during the dry months. If it is a subsoil supply, the probable variation in output is smaller, but the possibility of similar failure must be borne in mind. For this reason, wells should always be tested during

the dry season. If this is not possible, a liberal allowance must be made for the shrinkage of supply during the dry weather.

Again, it not infrequently happens that wells yield a good discharge to begin with but gradually become exhausted and, after a few years, cease to furnish an adequate supply. The probability of a failure of this kind may be, to some extent, judged from a knowledge of the behaviour of similar wells in the same district, but neither in this nor in any other problem relating to water-supply can anything quite definite be predicted. All we can do is to bear in mind the possibility of unforeseen contingencies and interpret our observations in a conservative manner.

The problem of calculating the developed supply from observed data may be stated symbolically as follows :—If, under a draught of a gallon per minute, the source is depressed b feet, what will be the depression under a draught x, the capacity of the proposed pump ?

It is evident that if during measurement we can employ a pumping appliance having the same discharge as that of the proposed pump, we can immediately determine the developed supply without further calculation. If the supply is intended for domestic purposes or if a pumping appliance actuated by animal power is to be employed, it is usually possible in the measurement test itself to determine the developed supply also. But wells are usually tested with a view to the installation of a pumping plant giving a discharge of at least 200 to 300 gallons a minute and appliances of this capacity are not readily to hand. In such cases, therefore, we have to estimate the developed discharge by a process of deduction from the observational data. There is undoubtedly a connexion between discharge curves under different draughts and if a series of observations were made under various conditions of draught, we should obtain a series of curves somewhat similar to those shown in the following diagram. If the connexion between curves under different discharges were known, it would be necessary to obtain only one discharge curve by observation and the others could be obtained by calculation. Hitherto, unfortunately no satisfactory relation has been worked out and the deduction of the probable supply from observational results is largely a matter of personal judgment. Even though no mathematical relation has been established between different discharge curves it will be found that the graphical method of estimating probable discharges will prove useful, for by inspection of the observation curves a very fair idea can be formed of the probable shape of the curve under the proposed draught.

In many cases, especially when the test is made on a borehole, the curve thus calculated will show so great a depression as to make it doubtful if, in practice, the amount of water contemplated could actually be withdrawn. The question then arises : how is the discharge to be augmented ? At first sight it might appear that an increase in the size of the well or borehole would help matters. So far as a borehole is concerned, the discharge can no doubt be largely increased by increasing the size. But this is simply due to the fact that the area of infiltration is very small indeed and prevents the access of water. With a diameter of 6 or 7 feet this difficulty is removed and a

glance at any of the formulæ (given in Chap. X) will show that an increase in r the radius of the well makes a very small increase in Q the quantity. In a previous chapter it has already been explained that an enlargement of a well adds little to the discharge and that the total quantity of water that can be pumped from the subsoil at any one point is limited and is not materially influenced by the size of the well. Except in very special cases, it is unsafe to reckon on a supply of much more than 300 gallons per minute (4-inch size) from any single well and 200 gallons per minute (3-inch size) will more frequently be the limit. If more water is required, the only thing to do is to increase the number of wells drawn on, care being taken to space them beyond the limits of interference. Large lift systems irrigated by a single source are thus out of the question, except in the special case of pumping from a flowing river.

Where boreholes are deep, it is usually impracticable to enlarge them to their full depth. In such cases, it will often be found advantageous to enlarge the topmost 20 feet or so. This will not increase the supply, but it will enable a certain reserve of water to be maintained. The use of perforated tubes may also prove beneficial.

One point connected with the sinking of bore-pipes into permeable strata may be touched upon here. It is sometimes imagined that there is some advantage in carrying the bore-pipe some distance into the stratum. In the best of cases the procedure is of no benefit whatever and in many cases it is positively harmful.

The area of infiltration into a borehole, being equal only to its cross section, is comparatively small and, if the stratum from which the water is withdrawn is at all fine,—as, for instance, fine sand,—the water, in rising, has sufficient velocity to carry with it a good deal of sand, which settles in the borehole and causes it to choke. The removal of this sand creates a hollow space in the stratum as shown in Fig. 10, but this does not affect velocities and, when pumping is resumed, the same thing happens again.

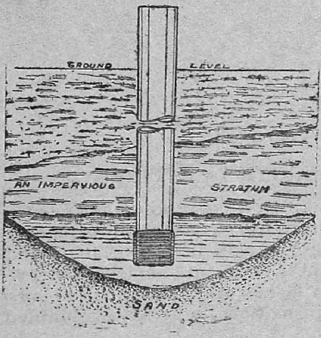


Fig. 10.

Ultimately after a long period the sand will be removed over a complete cone, shown in the figure, and then the area of percolation, being the surface of the cone, will have been so much increased and the velocity of the water passing across it so much reduced, that the water will no longer carry any sand with it. But to establish such a cone will take a great deal of time and till it is established the bore-pipe will constantly become choked. Further, when the cone is established, the upper layer of impervious material being unsupported over a considerable space will collapse and the trouble will begin all over again.

If, however, the bore-pipe is withdrawn so as only just to pass into the pervious stratum, as shown in Fig. 11, the hollow made before equilibrium is established is much smaller. The surface of the cone is large enough to reduce the velocity of percolation to a point when sand will not be carried whilst the base of the cone is sufficiently small to enable the superincumbent impervious stratum to span it without risk of collapse. Moreover a cone of this size can be established very quickly. It follows, therefore, that if a line pipe chokes persistently and fails to yield a proper supply, the withdrawal of the pipe to the upper edge of the pervious stratum may often lead to a marked improvement.

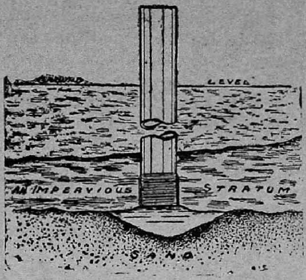


FIG. 11.

In hard rock it has often been found that the supply may be materially increased by blasting. A charge of about 5 lb. of dynamite is put down a borehole and then exploded. The shattering effect of this explosive causes a considerable pressing of the rock and thereby facilitates the access of water.

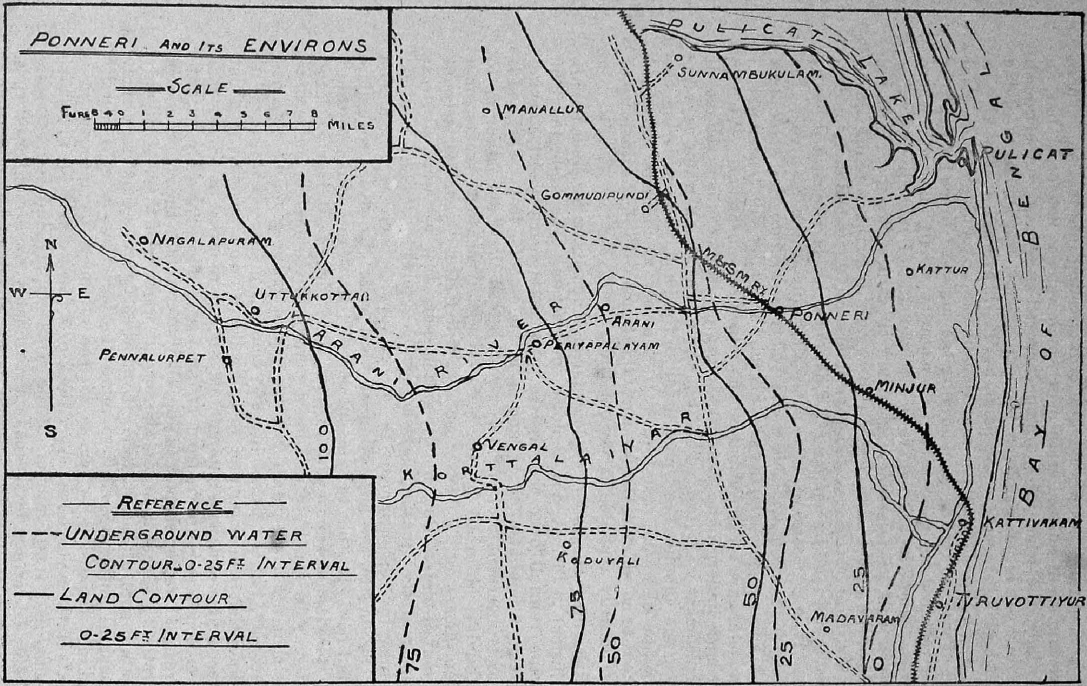
All these means of increasing supply should be tried before the estimation of the supply is undertaken.

CHAPTER XII.

THE MAPPING OF UNDERGROUND SUPPLIES.

As has been stated in a previous chapter, a beginning has recently been made by the Department of Industries in the mapping of underground water supplies. The work is as yet in its infancy and comparatively little has been done except in one taluk, namely, Ponnēri. A description of the results obtained will, however, be useful as indicating the general character of the information likely to be obtained from an underground water survey.

The area covered by the work already done is very limited and extends from Madras northwards for about 25 miles and westward as far as the railway line. This area is illustrated in the map given on the reverse and covers about 400 square miles. In it about 700 borings have been sunk and, for most of these borings, the surface level has been taken as well as the level of the water inside them. From the results thus obtained the position and level of underground water have been more or less determined. The surface and underground levels are indicated by contours.



The dotted lines across the map indicate the underground water contours.

The map furnishes a good deal of interesting information. There are certain small isolated areas over which water is not found but, on the whole, the whole of the land surveyed overlies a subterranean reservoir. It is impossible in the map to show the thickness of the water-bearing stratum at any point, but it will average at least 10—15 feet, which, assuming 30 per cent voids in sand, is equivalent to a solid sheet of water 5 feet deep underlying the surface. Since the depth of water required to bring a crop to maturity usually lies somewhere between 3 and 7 feet, it follows that the amount of underground water available will, with possible assistance from rain, suffice to irrigate the whole of the area it underlies. At first sight it might therefore appear that the whole of the area under consideration can immediately be converted to wet land by pumping. This conclusion is not justified by the data. It is a matter of little doubt that, during the first year, the underground water available would suffice to irrigate the whole area but, in subsequent years, the area actually irrigable will depend not on the amount of water stored but on the rate of replenishment. We may have large underground reservoirs to begin with but, unless the rate of replenishment is at least as great as the rate at which water is withdrawn, the supplies are bound to fail in time and, in considering the utilization of underground water, we are very much more interested in the rate at which replenishment takes place than in the quantity of water actually available at any one time.

Regarding the rate of replenishment, the data so far collected are insufficient to furnish any definite information. We know that the average rainfall over the area in question is nearly 4 feet, varying between a minimum of 1½ and a maximum of 7 feet. The land is flat and absorbent and probably two-thirds of the water falling on to the land is absorbed by the soil. We can therefore reckon on a replenishment of 2½ feet of subsoil water every year on account of rainfall only. But, for irrigation purposes, we want at least 5 feet and the question is whether the further 2½ feet can be obtained by replenishment in other ways. Such replenishment may be due to the absorption of flood water by rivers, to underground flow, etc., but the amount of water that can be thus absorbed and stored subterraneously we have little idea of: it may be large or it may be small. Speaking generally, I should feel inclined to state that not more than about one foot of water could be obtained in this way, but the figure given is merely a guess. If we accept it, we find that the maximum rate of replenishment amounts to about 3½ feet a year and, as a minimum of 5 feet is required, it follows that the subsoil water drawn from an area of 4 acres can only irrigate 3 acres. If replenishment is due solely to rainfall, the relation is in the ratio 2 : 1, that is to say, the subsoil water from 2 acres will only irrigate 1 acre of the surface. Even this figure seems reasonably promising until we recall to mind the fact that it is, generally speaking, impossible to remove all the subsoil water from a given area. If the reservoir is large, the 2 or 3 feet we propose to remove annually is a small fraction of the whole supply and can therefore probably be secured by means of a reasonably small number of wells. If, however, the reservoir is not large, the quantity of water mentioned may be equivalent to practically the whole of the underground supply and cannot therefore be withdrawn.

Thus, if the natural reservoir is large, we might count on being able to irrigate half the area by means of subsoil supplies, but in places where the underground reservoir is not so extensive we should have to be content with a much smaller fraction.

In other cases also, water may occur in sufficient quantity but the texture of the stratum in which it is found may be so fine as to prevent water being withdrawn sufficiently rapidly to make it worth while installing power for the purpose.

The question of underground supplies is not one that has attracted much attention, but there does exist a certain amount of literature on the point. This literature, however, mostly refers to European countries where conditions are very different from those met with in India. The only publication that contains any information of local interests is that by Dr. Smeeth (Note on Underground Water Resources in Mysore, Bangalore, 1911). Dr. Smeeth's researches are limited to Mysore where the conditions for water conservation are the worst possible. They are, therefore, of special interest as indicating what may be regarded as the minimum limit. Dr. Smeeth divides the surface soil into three zones, namely, (*a*) an upper zone called the zone of wetting, which gets wetted by percolation but does not remain so for long, as the water rapidly soaks through to a lower level; (*b*) an intermediate zone, called the zone of intermittent saturation, within which the annual fluctuations of water level occur, (*c*) a lower zone, called the zone of permanent saturation. In crystalline rock, of which the greater part of the Mysore plateau consists, the first zone is about 30 feet in depth, the second one about 10 feet and the third extends down to the limit of porosity. Dr. Smeeth is of opinion that in crystalline rock this limit is reached somewhere about 50 feet from the surface.

The amount of water that can be stored in the zone of intermittent saturation is the quantity that is permanently available and is estimated by Dr. Smeeth at about 15 inches. He also estimates the percentage of percolation at about 33 per cent. Hence, if the annual rainfall is in excess of 45 inches, we cannot store the excess and, if it is less, the amount of storage will be proportionately less also. As a matter of fact, Dr. Smeeth assumes that the whole of the supplies stored in the zone of intermittent saturation is not available and, on this account, he reduces the storage figure from 15 inches to 12 inches.

These results are interesting as indicating the general lines on which the underground water question is to be argued, but the figures obtained do not obviously apply to the Ponnēri taluk. We may make the same assumption of three zones and probably the upper zone will average about the same thickness as Dr. Smeeth's. The zone of intermittent saturation will also be of the same order of magnitude as in Dr. Smeeth's observations. In alluvial soil there will be no zone of permanent saturation as the water-bearing stratum will generally be sharply limited and defined by an underlying impervious stratum. This, however, is a small difference since the water capacity of the zone of permanent saturation in crystalline rock is very small. The principal difference between alluvial conditions and those described by Dr. Smeeth lies in the porosity. The porosity of sand is at least three

times as great as that given by Dr. Smeeth and in alluvium we should therefore expect at least three times the amount of available underground water, as compared with crystalline rock : that is about 3 feet, by percolation only.

Dr. Smeeth does not appear to take any account of water other than percolation water and it is to be inferred that he does not consider that supplies can be otherwise obtained, except no doubt by such exceptional means as underground rivers, etc. In crystalline rock it is difficult to see any justification for a theory of underground flow, but in alluvial soil, as already explained, there can be little doubt that some supplies are obtained otherwise than by direct percolation and it is regarding the character and extent of these extra supplies that underground water maps may be expected to furnish information of special value.

The map reproduced on page 70 covers only a small tract of country and cannot be regarded as typical of water conditions over larger areas. One feature of the map, however, deserves special notice.

As is to be expected, the water levels follow more or less closely the land levels and the general fall of the sub-soil water is towards the sea. Within 3 to 4 miles from the sea, it actually falls below sea level, although it still remains fresh. The average fall of the sub-soil water is about 4 feet in a mile.

Mr. Chatterton places the limiting slope for water in sand at about 1 in 250 and beyond that gradient he asserts that there is no appreciable motion of water. Assuming a gradient of 1 in 264, equivalent to 20 feet a mile, it follows that, if lower basins are to be replenished by water flowing from higher ones, the underground water table must have an inclination of at least this figure. At sea level the underground water level is 10 feet below that level. To satisfy the conditions for flow it must be at least 200 feet higher, or say 190 feet above sea level at a point 10 miles inland. The land surface at such a point is only 60 feet above sea level and it is thus clear that no replenishment of supplies in the lower basins can be supposed on Mr. Chatterton's theory except by direct infiltration from rivers. The supply obtained in this way cannot be very large and we are still left in doubt as to how supplies are replenished otherwise than by percolation.

The way in which an answer to this question of supplies must be obtained is by noting the variations in water level of certain selected wells over a long period, as has been done by Dr. Smeeth. This will establish the extent of the zone of intermittent saturation and, by subtracting such part of the supply as is obviously traceable to direct percolation, we obtain an idea of the amount of water otherwise procured. Observations of this character are now being instituted but the information so far collected is insufficient to justify any conclusions.

Work is at present being carried out also in the Tanjore district but the number of observations is at present insufficient to enable a map to be drawn. The character of the underground water supplies in the Tanjore delta is very different from that illustrated in the map. For one thing, the supplies are much more deep-seated and, for another,

they are of a much more discontinuous character. The Coimbatore district will give still more divergent results since here we are dealing with crystalline rock in which the distribution of underground water is along lines rather than over surfaces. Coimbatore results will probably agree very closely with Dr. Smeeth's.

The whole of this underground survey work is still in its infancy, and it will be many years before the data collected will be sufficiently numerous to enable accurate deductions to be made. The general issues discussed in the light of the few data we already have should, however, serve to show how large a field for enquiry this question of underground water opens up and what important results may be expected when it has progressed sufficiently for scientific study.

BIBLIOGRAPHY.

Well boring for water, brine and oil—C. Isler.

The control of water—Parker—Routledge, 1913.

Note on the Underground Water Resources in Mysore—Smeeth.—Government Press, Bangalore, 1911.

Geology of India—Oldham—Government Press, Calcutta.

Wells and their yield—Close—R.E. Institute, Chatham.

Water supply—Hubbard and Keirsted—Wiley, New York.

Lift Irrigation—A. Chatterton—Natesan, Madras.

Administration Report of the Department of Industries—Passim.

Distribution d'Eau—Debanne.

Experiments on passage of water through sand—Clibbom—Roorkee, 1896.

Bewegung des Wassers—Hubbe—Zeitschr. f. Bauw, 1861.

Handbuch d Wasserbaukunst—Hagen—1856.

Theorie des puits artesiennes—S. B. Viollett—Paris, 1840.

Inflow of water into wells—Hilton—Indian Engineer, 1892.

Filtration of water—Hazen.

Inflow of water into wells—Western—Indian Engineering, 1892.

Forchiemer—Ztschr. Oestr. Ing.—1898.

Manual of Irrigation wells—E. A. Molony—Government Press, Allahabad, 1907.

D1:14
N18

TAMIL NADU ARCHIVES LIBRARY
No. 25793
EGMORE MADRAS